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ABSTRACT

This volume presents a compilation and review of more than 400 research studies on science teaching and the preparation of science teachers that were reported in 1988, organized into 10 sections. The sections are: (1) "Professional Concerns"; (2) "Teacher Education"; (3) "Programs"; (4) "Curriculum"; (5) "Instruction"; (6) "Conceptual Development"; (7) "Problem Solving"; (8) "Achievement"; (9) "Attitude"; and (10) "Epistemology." Each major section begins with an overview of the research summarized in the section and a context for review, and ends with an invited commentary on the impact and implications of the research presented in that section. A master bibliography is appended. (CW)

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A SUMMARY OF RESEARCH
IN
SCIENCE EDUCATION — 1988

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Contents

PREFACE i

ACKNOWLEDGEMENT ii

INTRODUCTION 1

1.0 PROFESSIONAL CONCERNS 5

- 1.1 Technology and the Profession 5
  - 1.11 What impact has computer technology had on teachers? 5
  - 1.12 What impact has computer technology had on students? 6
  - 1.13 What impact has computer technology had on research? 7
  - 1.14 In what ways does computer technology affect learning? 8
- 1.2 Research and Practice 10
  - 1.21 How can research improve teaching? 10
  - 1.22 How do policy and goals influence science education? 10
  - 1.23 What are some of the major research findings with implications for the future? 12
- 1.3 Issues in the Profession 14
  - 1.31 In what ways can business influence practice? 14
  - 1.32 What gender differences are related to teaching practices and career choices? 14
- 1.4 Invited Commentary — Dorothy Gabel 15

2.0 TEACHER EDUCATION 18

- 2.1 Status of Teacher Education 18
  - 2.11 What is the status of teacher education in select regions of the U.S.? 18
  - 2.12 What is the status of teacher education in Jordan, Malaysia and Thailand? 19
  - 2.13 What factors facilitate classroom teachers as educational innovators? 20
  - 2.14 What school reforms would entice certified but non-teaching graduates back to the classroom? 20
  - 2.15 What academic factors complement the teaching of evolution? 20
  - 2.16 How highly do school administrators rate teachers? 21
  - 2.17 How important are induction programs to beginning teachers? 21
  - 2.18 How well do science majors planning to teach compare to their non-teaching counterparts? 22

2.2 Preservice Teacher Education 22

2.21 How do select teaching strategies and instructional packages affect teaching effectiveness? 22
2.22 How effective is the integrated professional semester? 24
2.23 Does locus of control influence teacher education? 24
2.24 Do sign-language lessons for biology students influence the teaching effectiveness of deaf student teachers? 25
2.25 What instruments are under development for preservice teachers? 25

2.3 Inservice Teacher Education 26

2.31 What is the impact of summer institutes and other strategies on staff development? 26
2.32 Does computer conferencing facilitate staff development? 27
2.33 Are teachers with limited knowledge prone to restrain classroom discourse? 28

2.4 Invited Commentary — David P. Butts 28

3.0 **PROGRAMS** 32

3.1 Status of Programs 32

3.11 What is the status of programs in selected states and regions of the United States? 32
3.12 What is the status of programs in African nations? 33
3.13 What is the status of earth science programs? 33
3.14 What is the status of energy education? 34

3.2 Perceptions of Programs 34

3.21 What perceptions are held by the public regarding public school programs? 34
3.22 What factors other than programs affect students' perceptions of science? 35

3.3 Program Evaluation 36

3.31 How do process-oriented and textbook-based curricula compare? 36
3.32 What are the cognitive demands of Alternative Nuffield Physics? 37

3.4 Exemplary Programs and Their Attributes 37

3.41 What attributes are common to programs identified as exemplary? 37
3.42 What characteristics are common among exemplary teachers? 39

3.5 Invited Commentary — Frances Lawrenz 40

4.0 CURRICULUM 44

4.1 Learning in Nonformal Settings 44

4.11 What factors influence attentional behaviors in museums? 44
4.12 What variables are common among zoomobile programs? 44
4.13 How do formal, nonformal, and informal learning experiences compare? 44

4.2 Science-Technology-Society 45

4.21 Are the processes emphasized by Science-Technology-Society part of the standard high school curriculum? 45
4.22 How are religious orientation and attitudes toward Science-Technology-Society issues related? 45
4.23 How do experiences with a Science-Technology-Society focus compare with traditional experiences? 45
4.24 What is the preferred testing format for assessing students' beliefs about Science-Technology-Society topics? 46

4.3 Textbooks 46

4.31 Is the reading level of textbooks too difficult? 46
4.32 How do elementary textbooks compare? 47
4.33 Is stereotyping common in elementary textbooks? 47
4.34 How is theory treated in middle school life science textbooks? 48
4.35 How are unifying concepts presented in textbooks? 48
4.36 How are methods of evaluating reading materials related? 48
4.37 How do students approach a new reading assignment? 49
4.38 Does decision-making augment recall of text material? 49

4.4 Curriculum Development 50

4.41 What are the results of curriculum development efforts? 50
4.42 How related are the intended, translated, and achieved physics curriculum? 50
4.43 What is the effect of pre-planning evaluation on curriculum development? 50
4.44 What effort is being invested to develop teachers' assessment skills? 51
4.45 How promising is student involvement in curriculum reform? 51

4.5 Invited Commentary — Glen Aikenhead 52

5.0 INSTRUCTION 54

5.1 Teaching Methods and Strategies 54

5.11 What are the effects of alternative forms of instruction on student learning? 54
5.12 What are the effects of cooperative and individualized mastery learning on achievement and on-task behavior? 56
5.13 What expository styles of teaching are predominant among teachers in African nations? 57
5.14 What factors relate to inquiry as utilized by secondary teachers? 57
5.15 How are process-oriented teachers unique in teaching behaviors? 58
5.16 Do physics teachers follow similar instructional patterns when presenting the same topic? 58

5.2 Learning Environment 58

5.21 What factors foster a harmonious student-centered learning environment? 58
5.22 What is the relationship between students' perceptions of the learning environment and learning outcomes? 59

5.3 Learning Cycle 59

5.31 Are all phases of the learning cycle necessary? 59

5.4 Invited Commentary — Ken Tobin 59

6.0 CONCEPTUAL DEVELOPMENT 63

6.1 Research on Conceptual Development 63

6.11 What is the status of research on conceptual development? 63

6.2 Descriptive Studies of Alternative Conceptions 64

6.21 What term best describes students' conceptions? 64
6.22 What alternative conceptions do students possess in the biological and physical sciences? 64
6.23 Do teachers harbor the same alternative conceptions as their students? 71

6.3 Research on Reasoning Skills 71

6.31 Can students' logical thinking abilities be reliably measured? 71
6.32 To what extent does instruction develop students' reasoning skills? 71
6.33 What relationships exist between reasoning ability and conceptual development? 74

6.4 Conceptual Change Studies 76
    6.41 Can the misconceptions of students be altered by select instructional methods? 76
    6.42 How does instruction targeting conceptual change affect the performance of students during the succeeding year? 79
6.5 Invited Commentary — Larry Yore 79
7.0 PROBLEM SOLVING 82
7.1 Characteristics of Experts and Novices 82
    7.11 How do subjects perform when solving genetics problems? 82
    7.12 How do subjects perform when solving chemical equilibrium problems? 83
    7.13 How do subjects perform when solving mechanics problems? 84
7.2 Factors Related to Success at Problem-Solving 86
    7.21 What are the unique attributes to problem-solving? 86
    7.22 What is the nature of genetics problems? 86
    7.23 What cognitive strategies are utilized when solving problems? 86
7.3 Success Among Members of Special Populations 90
    7.31 Are members of special populations differentially effective at problem-solving? 90
7.4 Experiments Designed to Improve Problem-Solving Skills 92
    7.41 What can be done to improve learners' cognitive abilities? 92
    7.42 How can problem-solving skills be improved? 93
    7.43 How can subject-specific problem-solving skills be improved? 94
7.5 Invited Commentary — Joe Krajcik 95
8.0 ACHIEVEMENT 100
8.1 Status of Achievement 100
    8.11 What is the status of achievement in New York City? 100
    8.12 How knowledgeable are students about the ocean and the Great Lakes? 100
    8.13 How knowledgeable are students about health and physical fitness? 101
    8.14 How well informed are students about acidic deposition? 101
    8.15 How learned are college students about models and model building? 101

8.2 Correlates of Achievement 102

8.21 Which learner characteristics relate to achievement? 102
8.22 What factors combined with learner characteristics relate to achievement? 104

8.3 Interventions and Achievement 106

8.31 What instructional interventions affect achievement? 106
8.32 What are the effects of parental involvement on achievement? 108
8.33 Do pre-instructional experiences affect chemistry achievement in college? 108
8.34 Does the matching of students and teachers on cognitive style affect achievement? 109

8.4 Perceptions of Achievement 109

8.41 What knowledge, skills, and personal attributes are perceived to be important for high school students planning to study biology in college? 109

8.5 Gender Differences and Achievement 109

8.51 What is the relationship between gender and achievement? 109

8.6 Process Skill Attainment 111

8.61 What factors relate to student proficiency in the use of process skills? 111
8.62 Do hierarchical relationships exist among process skills? 113
8.63 Does question format affect performance on a written test of process skills? 114

8.7 Invited Commentary — John Staver 114

9.0 ATTITUDE 117

9.1 Affective Constructs and Their Relations 117

9.11 What is attitude and how is it related to other affective constructs? 117

9.2 Determinants of Science-Related Behaviors 118

9.21 What factors are associated with science-related behaviors? 118
9.22 What is the efficacy of the Theory of Reasoned Action for understanding and predicting science-related behavior? 119

9.3 Beliefs and Attitudes Regarding School Science....119

9.31 What are the attitudes of gifted students?....119
9.32 What are teachers' beliefs regarding the importance of laboratory work?....120
9.33 What do teachers and students think about the use of video programs?....120

9.4 Factors Relating to Attitudes, Interests, and Other Affective Variables....120

9.41 What school and cultural factors are related to attitude, interest, and other affective variables?....120
9.42 What affective variables are related to achievement?....122
9.43 What teaching strategies enhance attitudes, interests, and other affective variables?....123

9.5 Instrumentation in the Affective Domain....124

9.51 What new instruments are available to assess affective concepts?....124

9.6 Invited Commentary — Hugh Munby....125

10.0 Epistemology....130

10.1 Nature of Science....130

10.11 What ideologies should undergird instruction and curricula development?....130
10.12 What is the valid pedagogical role of "description" and "explanation" in the classroom?....131
10.13 What are some of the functional paradigms operating in the classroom setting?....132

10.2 World View....132

10.21 How are world views of science manifested by teachers and students?....132
10.22 Can world view research facilitate the understanding of misconception research?....133

10.3 Invited Commentary — Richard Duschl....133

References....138

Preface

The Summary of Research in Science Education series has been produced to analyze and synthesize research related to the teaching and learning of science completed during a one-year period of time. These summaries are developed in cooperation with the National Association for Research in Science Teaching. Individuals identified by the NARST Research Committee work with staff of the ERIC Clearinghouse for Science, Mathematics, and Environmental Education and the SMEAC Information Reference Center to review, evaluate, analyze, and report research results. The purpose of the summaries is to provide research information for practitioners and development personnel, ideas for future research, as well as an indication of trends in science education research.

Readers comments and suggestions for the series are invited.

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Acknowledgement

We are grateful for the assistance of Stan Helgeson and the ERIC staff for promptly mailing a complete set of science education research reports to us, abstracted and entered into the ERIC and DAI databases during 1988. The three of us were pleased — even flattered — to be asked to review the science education research for 1988. We owe a special debt of gratitude, however, to our colleagues who took time out from their busy schedules to accept our invitation to serve as reactants to the chapters contained in this, A Summary of Research in Science Education — 1988. Without their insightful commentaries it would have been impossible to fulfill our goal of producing an accurate record of science education research for 1988 and of charting directions for future investigations in the profession. Our thanks go out to the following persons:

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Introduction

Like past reviewers who have undertaken this task, our main goal was to organize the research in a manner in which studies on related topics could be easily accessed. In considering this goal we thought about the purposes served by an annual summary of research in science education and arrived at three desired ends. First of all, the summary can function as a historical record of the research reported during a single calendar year. By examining consecutive annual summaries, a reader can recognize trends in the research and note priorities and cessations in the coverage of particular themes. Secondly, a summary can be of assistance to science educators, researchers and practitioners, in maintaining currency in sub-areas of the research, providing readers with state-of-the-art links to ongoing research in the discipline. And finally, an annual summary can serve to fashion future research in science education for beginning researchers and veterans as well. Our thoughts about the purposes of an annual research summary led us to adopt an organizational structure that stems from what we perceive to be the prominent foci of today's research in science education. Therefore, this year's summary is organized around 10 major groupings arranged by chapters as follows:

Chapter One, **Professional Concerns**, synthesizes studies that investigated concerns regarding technology, research and practice, and issues in science education ranging from business and education partnerships to state-mandated accountability. It is topics of this nature that shape, mold, and direct the research and practice of science education at all levels.

Chapter Two, **Teacher Education**, synthesizes studies that focused on the status of teacher education in the United States and elsewhere, examining preservice and inservice programs and means for improving the profession. Teacher education, it can be argued, serves as the foundation upon which the future of the profession rests.

Chapter Three, **Programs**, highlights studies that investigated the status and perceptions of traditional and exemplary science programs and program evaluation. Few new science programs were unveiled in 1988, but program assessment seemed to be on the increase. Assessment is an integral part of both program development and improvement. Not surprisingly, status and program evaluation studies dominated the research reported in this area during 1988. New to the scene are studies of exemplary programs in Australia.

Chapter Four, **Curriculum**, focuses on studies that investigated science learning in nonformal settings, issues related to Science-Technology-Society (STS) objectives, textbooks, and curriculum development. The controversy surrounding STS versus traditional curricula seems to have subsided, as outcomes of both approaches are now being documented. The textbook and its uses were given careful attention by researchers interested in curriculum studies.

Chapter Five, **Instruction**, summarizes studies that examined teaching methods and strategies and the learning environment. Alternative instructional methods and strategies remain areas of interest. Most prominent among the instructional research reported in 1988 are studies that compare "traditional" instruction with alternative forms. Studies of the total science learning environment seem to be gaining popularity.

Chapter Six, **Conceptual Development**, synthesizes studies that address the status of conceptual development research, reasoning skills, and alternative conceptions held by the learner and means by which they can be changed. Considerable progress has been witnessed in the research pertaining to conceptual development and metacognition. No longer are researchers solely engaged in descriptive studies. As evidenced by reports included in this chapter, the knowledge base is developed to the point that experimental studies have begun to appear.

Chapter Seven, **Problem Solving**, reports on studies that explored characteristics of expert and novice problem solvers, factors related to success at problem-solving, problem-solving among special groups, and interventions designed to improve problem-solving. Progress in the study of problem-solving mirrors that of conceptual development research. Experimental studies conducted during 1988 propose to improve general and specific problem-solving skills as well as the cognitive abilities of learners.

Chapter Eight, **Achievement**, summarizes studies that investigated the status of science achievement, correlates and perceptions of science achievement, the effect of gender differences and interventions on achievement, and process skill attainment. Brought to light in this chapter are the disturbing results of the Second International Education

Assessment in Science Study but with the newly added dimensions pertaining to specific outcomes and teaching practices.

Chapter Nine, **Attitude**, reviews studies that investigated affective constructs and their interrelations, determinants of behaviors, attitude measurement, and student and teacher-held, science-related attitudes and beliefs. Science education research in the affective domain has been strongly criticized over the years. It has been called "chaotic," "disappointing," and "inconclusive." Nonetheless, research in the affective domain was vigorously pursued in 1988, spurred by the merging of cognitive and behavioral approaches into a more rigorous, empirically-supported theoretical base.

Chapter Ten, **Epistemology**, chronicles studies that focused on the nature of science and world views of science. The number of entries in this chapter, however, belies its importance. Though silent and unassuming, the meta-messages communicated to students by the ideologies, paradigms, and teaching methodologies operant in the classroom may well direct the educational health of the profession.

As we further contemplated the task of writing this year's summary of research, we came to view it as an opportunity not only to synthesize the research reported in 1988 but to have a voice in setting the research agenda for our discipline well into the 1990s. With this challenge in mind, we decided to break new ground with this year's summary. We invited colleagues, distinguished for their expertise in select areas of research in science education, to comment on our synthesis. The charge given to these experts was to construct a written commentary that acknowledges sound research efforts and offers suggestions regarding how to remedy problems noted in the research reported in 1988 and summarized for that year. In addition, each person was asked to recommend future directions for research in the area of his or her expertise. An invited commentary follows each chapter included in this year's summary. We are greatly indebted to our colleagues who gave of their time and energies to help us realize and fulfill our vision.

Bibliographic data provided by SMEAC served as the point of departure for our summary. We were supplied with a listing of over 300 citations accompanied by abstracts of studies either published or reported during the year 1988. Dissertations reported in Dissertation Abstracts International (DAI), articles abstracted for inclusion in Current Index to Journals in Education, and reports cited in Resources in Education (RIE) functioned as our primary data base. Because it was not always possible to prepare a succinct report of the study and its findings using information provided by SMEAC, original sources were often consulted. Getting our hands on dissertations proved to be more difficult than locating journals and reports cited in RIE. As a result, the author's abstract prepared for DAI more often than we would like served as the sole source for our summary. Furthermore, we made no attempt to seek out reports transmitted in sources beyond the customary boundaries of science education, namely sources abstracted for inclusion in the DAI and ERIC data bases. To do otherwise would have made it difficult, if not impossible, to draw the line on sources to be included in the summary and those to be omitted, caused unnecessary manuscript delays, and only served to increase the summary to an unmanageable length. As reviewers for the year 1988, we take full responsibility for any shortcomings and omissions identified in this summary.

We feel obliged to issue one final precautionary note about the invited commentaries. Research studies included in the review for 1988, the reader must realize, were conducted six months to two years prior to being reported by their author(s). The studies thus become "free game" and the authors easy targets for criticism without benefit of rebuttal. Reviewers enjoy the benefit of historical hindsight, unavailable to the author(s) of the original reports, and they make use of recently published and "in press" reports to construct their commentaries.

Closing Remarks

Underlying the organization of this summary is our dissatisfaction with the fragmented character of science education research. Our discipline's problem is one of integrating bits and pieces of validated information into a systematic and adequate set of general principles that direct the profession of science education and the practice of science teaching and learning. This volume with its invited commentaries, representing diverse interests, will not satisfy those persons who seek and find solace in a single focus for science education research — though constructivism and developmental psychology themes permeate studies included in the 1988 Review. But it is more than the typical summary of research with its compilation of studies and findings. It does, we think, serve to advance research efforts in the science education community of scholars and to move us forward toward the desired goal of improving science teaching and learning through research. This year's summary, we assert, provides a snapshot of research in science education, brings together authors who emphasize the relationships within and across sub-areas of our discipline, and makes available a forum for some of our profession's most distinguished contributors to offer their noteworthy insight and critique.

1.0 Professional Concerns

Studies included in this chapter are of interest to all science educators engaged in research and teacher training, preservice or inservice. Three categories of studies are reviewed: technology and the profession (18 studies), research and practice in science education (14 studies), and issues in the profession (4 studies). The technology and the profession section includes studies on the impact of computers and computer technology on teachers, students, research, and learning. Studies included in the research and practice section include improved research practices, research linked with practice, state indicators of science-mathematics teacher quality, teachers' conceptions of the contemporary goals of science education, and research conducted in non-US settings. This chapter concludes with issues in the profession, including reports relevant to gender differences and instruction, state-mandated accountability, science and job training, business-education partnerships, and factors related to women's entry into science and related careers.

1.1 Technology and the Profession

1.11 What impact has computer technology had on teachers?

Using the Concerns Based Adoption Model, **Butzow** reported on a project designed to assist science and mathematics teachers to use computer-based, activity-teaching for their classrooms. During the summers of 1986 and 1987, two populations of inservice science and mathematics teachers participated in workshops designed to assist them in the use of computer-based, activity-teaching for imparting science and mathematics content in their classrooms. Using the Stages of Concern Questionnaire, teachers in the first group recorded significant reductions in the first three stages of concern with "refocusing" the only stage to emerge as a major concern. Delayed posttest results differed little from responses attained at the conclusion of the workshop.

Ellis and Kuerbis reported the results of a model for implementing educational computing in science, conducted at the Biological Sciences Curriculum Study (BSCS) and funded by the National Science Foundation. The project met its first year objective of increasing science teachers' use of microcomputers. Implementation adhered to the guidelines of the Concerns Based Adoption Model (CBAM). Results of pre- and posttests using the Stages of Concern Questionnaire indicated that the participant profile changed from non-user to user. Most of the participants employed microcomputers in several ways by the end of the year.

A series of computer-based activities was developed by **Lehman** and integrated into the laboratory of a two-semester biology course for elementary teaching majors. Groups completing supplemental computer-based activities were compared to non-computer groups on achievement and measures of attitudes toward computers, biology, and the supplemental activities. Few achievement differences were realized. Some students expressed favorable evaluations of the computer-based activities, and students showed significantly more positive attitudes toward computers. The findings suggest that the integration of computer-based instruction in college coursework may be an effective means of incorporating computer education into preservice teacher education.

The use of microcomputer-based simulation in the preparation of secondary science teachers was studied by **Shyu**. The microcomputer classroom simulation enlisted experienced teachers, to provide prospective secondary science teachers with laboratory experiences in classroom management and to study the impact of the simulation on prospective teachers. Also, the management concerns of science teachers in Taiwan were compared with those of U.S. teachers to determine if the simulation results in different effects on prospective teachers of different cultural backgrounds. The study revealed that simulation provided prospective science teachers with an opportunity to practice classroom management strategies. The responses of American and Chinese teachers varied on certain management strategies and discipline problems, and the simulation had less impact on American students. In addition, no differences were observed in teaching performance between American teachers in experimental and control groups, but subjects in the former group expressed positive attitudes toward the simulation.

In a study of the nature and extent of utilization of computer technology in Texas' classrooms, **Mitchell** surveyed a random sample of 2000 secondary science teachers. An initial survey sought information on the extent of current use of computer technology. A second survey was sent to teachers reported to be users on the first survey. Few teachers were found to be users (17%), with more teachers (40%) anticipating use of computers within the next two years. Lack of resources and opportunities were identified as the main reasons for non-use. Computer-assisted instruction was found to be the most popular use, with a trend toward tool applications. Mitchell concludes that secondary science teachers in Texas are only in the beginning stages of computer implementation.

1.12 What impact has computer technology had on students?

Wilson reported on more than 15 collaborative research projects conducted by members of the Educational Technology Center to study the use of computers and other technologies to improve K-12 instruction in science, mathematics, and computing. Team members focused on "Targets of Difficulty", curricular topics that are both crucial to students' progress in these fields and widely recognized as difficult to teach and learn. The findings had implications for teaching and learning, technology, and implementation. Computers, it was concluded, have the potential to help students develop understanding by accounting for their intuitive theories and misconceptions, and by integrating direct instruction with the exploration of problems. Technology should be used selectively, for example, to present dynamic visual models of key ideas, to help students gather and display data, to allow them to construct and manipulate screen objects such as graphs or geometric figures, and to give teachers and researchers a window on students' thinking and learning. Wilson recommends that practitioners be included in all phases of research to ensure that the technology-enhanced teaching approaches will fit with current curriculum and instruction.

1.13 What impact has computer technology had on research?

A joint project between science educators and computer software engineers was undertaken to develop a software system based on cognitive learning theory. The generic prototype software system, reported by **Koch, McGarry, and Patterson**, serves three purposes: it aids instructors and students of science in the construction of a meaningful knowledge base through concept mapping; it serves as an intelligent, individualized, and interactive tutor for learning the concepts and conceptual relationships in a specified knowledge domain; and, it generates a database for subsequent analyses and research on student misconceptions, and how these might change through computer-based instruction. The data base generated by the software program can direct subsequent construction, modification, or improvement of curricula.

Krajcik, Simmons, and Lunetta designed and evaluated a research strategy for assessing student learning. A major feature of the strategy included recording students' interaction with microcomputer software interfaced with a video cassette recorder (VCR). The VCR recorded the output from a microcomputer along with verbal commentary via microphone, thereby recording simultaneously students' comments about their observations, perceptions, predictions, explanations, and decisions with their computer input and the display on the microcomputer monitor. The open-ended research strategy, according to the authors, can extend our understanding of cognitive and affective behaviors of students and how they interact with computer software.

The effect of computer-assisted instruction and learning differences on science concepts was investigated by **Rowland**. Elementary education majors learned about home energy use from either a computer simulation or a computer tutorial. Four individual learning styles were assessed, as were achievement and applications. Achievement test scores were higher for tutorial users than for simulation users, but no differences were found in application. Increased discrimination skill raised scores of tutorial users but decreased scores of simulation users. Holistic learning strategies were reported to be superior to serialist strategies on the test assessing application.

Asserting that laboratory experience does not help students understand the ideas of scientists, **Snir, Smith, and Grosslight** advance a rationale for designing conceptually-enhanced microcomputer simulations and describe their underlying structure. Natural phenomena and model systems are described, especially the systems that help students understand the theoretical framework of scientific thinking. These ideas are applied in simulations that teach the concepts of weight and density.

1.14 In what ways does computer technology affect learning?

The effects of microcomputer-based laboratory (MBL) exercises and level of cognitive development on students' ability to construct and interpret line graphs was the subject of a study reported by **Adams and Shrum**. Twenty student volunteers enrolled in general biology classes at a rural high school were the participants. Students in the experimental group completed laboratory exercises using a microcomputer to gather, display, and graph data. Students in the control group completed the same four laboratory exercises using conventional laboratory equipment, and they produced line graphs by hand. Students completing MBL exercises outperformed control group students on graph interpretations, but students in the control group were superior on graph construction. Students classified as high on cognitive development outscored students classified as low.

In a study of students enrolled in general physics classes at a two year liberal arts college, **McCurry** tested the effects of microcomputer drill and practice in problem solving on achievement and attitude. Twenty-three students were assigned to a microcomputer drill and practice group or traditional drill and practice group for two physics units, each unit three weeks long. Treatments were reversed for the second of the two units. Results revealed no differences in the experimental and control groups on achievement or on two subscales of achievement, namely problems requiring recall and those requiring higher level thinking. Larger gains, however, were earned by those in the microcomputer group. McCurry reports no significant differences in students' attitude toward physics, use of microcomputers in physics instruction, or computers.

Using the Chemistry Tutor software package, **Mousa** assessed the effects of computer-assisted instruction (CAI) on college students' achievement and performance in balancing chemical equations. Experimental subjects received 120 minutes of tutorial instruction. Data sources included pre- and posttests measuring student abilities to balance chemical equations, a checklist providing background information, and videotapes of student interactions with the CAI tutorial. Differences in balancing equations were found between pre- and posttests. Most students' scores improved on the posttest, and achievement was associated with prior experience with computers and chemistry. In addition, the number of estimates per problem decreased with time, and the time required for estimates was reduced. Students quickly cast aside computer assistance as they develop more efficient strategies for balancing chemical equations.

Research reported by **Brasell** assessed the impact of a microcomputer-based laboratory (MBL) employed by high school students. Here they developed a cognitive linkage between a physical movement event and the Cartesian graph of either distance or velocity displayed on the computer screen. The impact of real-time graphing was isolated by delaying the graph display for 20-30 seconds but otherwise leaving the activity identical. The real-time and delayed treatments were compared to pencil-and-paper graphing. Using a pretest-posttest design data analyses revealed that students in the real-time MBL group recorded lower error rates on the posttest than did students in either the delayed-time MBL or the pencil-and-paper groups. Real-time graphing seemed to improve motivation and provide a sense of competence and achievement. Some attitude and performance differences were attributed to gender.

Computer-assisted instruction (CAI) was compared with paper-and-pencil instruction and a no-intervention group in a study conducted by **Hauben and Lehmen**. Assessed were the impact of CAI on problem solving in chemistry and attitudes in chemistry. The subjects were volunteers enrolled in a chemistry course for under- prepared students. Fifty-seven students were randomly assigned to CAI or paper-and-pencil instruction, and twenty-eight non-participants enrolled in the course served as the control group. Scores were obtained on immediate and delayed achievement measures, results of pertinent items on a quiz given two days later, and results of the final exam. Seven Likert-type items assessed student attitudes toward the CAI and paper-and-pencil modules. Results disclosed that the CAI group was superior to the paper-and-pencil group on volume and word problems. On the retention test, the CAI group outscored both the pencil-and-paper and the control groups on simple problems. On complex problems, the CAI group scored lower than the pencil-and-paper and the control groups. Student attitude favored the CAI group.

Constant studied student learning of motion concepts and integrated process skills by computer simulation. Programs from The Simulated Amusement Park and accompanying activity sheets served as instructional material with 61 urban, middle school students, who were assigned to one of two instructional groups. One group of students had access to one computer for demonstration. The other group of students worked in pairs in a computer-lab setting. Learning was assessed with the Informal Science Study (IfSS) Content Test and the Test of Integrated Process Skills (TIPS II). Students' science grades, their prior amusement park experiences included in the simulations, and their computer experience were also collected. Constant reports significant increases in learning for both groups, but no differences were attributable to instruction, gender, age, or experience with amusement park rides or computers.

Ostojic evaluated the status of the chemistry placement test at the University of Illinois at Chicago (UIC). Also, a reduced-scale computerized-adaptive place test (CAT) was studied. A telephone survey of 50 U.S. universities and colleges revealed that about one-third used chemistry placement tests. About two-thirds of the items on UIC's test required revision or replacement. Increased on the revised placement test were the following: average item-total difficulty, average item correlation value, and student success.

The status of computer programming in secondary schools in the People's Republic of China was studied by **Chen Qi**. An optional computer course in BASIC programming was introduced in university-affiliated senior high schools in Beijing, Shanghai, and Guang-zhou. Three studies sought to determine who learns best from programming courses and students' attitudes toward these courses. Programming skill correlated significantly with mathematics ability, the final mathematics examination score, paper folding, and surface development. Not significant were the correlations between programming and verbal ability, hidden patterns, and Raven's matrices. Teachers and students thought the computer course was necessary and that it helped students learn. Moreover, teachers and most senior high students reported that programming is appropriate for the junior high school students as well.

1.2 Research and Practice

1.21 How can research improve teaching?

Addressing the problem of translating research into classroom use, **Howe** described a model where university researchers and classroom teachers collaborated to test, evaluate, and adapt research to classroom settings. Identifying the interest of science and mathematics teachers in research was the first step. Forming a team of researchers and teachers to discuss means of integrating research and teaching, followed. The final step was reaching consensus among teachers on implementation. Groups of teachers and university faculty have emerged who are improving science and mathematics education. Research has been reflected in curricular materials and instruction.

Action-oriented research may present problems when the researcher is present during instruction. **Scott** employed a naturalistic inquiry technique in a rural, seventh grade science class to investigate the effect of researcher presence on a class. Initially, the presence of a researcher had a dampening effect on student interactions. However, Scott reports that by the third visit student interactions had been normalized so that the researcher was included in conversations and exchanges.

1.22 How do policy and goals influence science education?

Scientists, educators, and researchers participated in a symposium convened by the Committee on Research in Mathematics, Science, and

Technology Education of the National Research Council for the purpose of exploring research related to teacher quality in science and mathematics. **Blank** (a) reported the results of participants' discussions on teacher quality, the types of research needed, and the issues that could be addressed by further research. The major findings of the symposium were organized into six categories: Recruitment and Selection of Teachers, Education of Teachers: Subject Matter Proficiency, Education of Teachers: Development of Teaching Skills, Effects of Teaching Practices, Conditions Fostering Quality Teaching, and Societal Issues Related to Teacher Quality.

The State Assessment Center of the Council of Chief State School Officers sponsored a project, reported by **Blank** (b), to develop state indicators of the condition of science and mathematics education in elementary and secondary schools. Results of a survey identified six areas of information needed to monitor the condition of science and mathematics education. The areas include the following: Student Outcomes, Instructional Time and Enrollment, Curriculum Content, School Conditions, Teachers, and Equity.

Do teachers support contemporary goals in science education over goals of the 1960s? **McIntosh and Zeidler** surveyed and analyzed the beliefs of middle and high school science teachers in the State of Delaware (47% of 307 responded). Participants were given a bipolar scale with the major goals of the 1960s at one pole and corresponding objectives of the 1980s at the other pole. Results of the survey indicated a majority of the science teachers lacked commitment to modern goals of science education. However, teachers committed to modern goals felt stronger in their conviction than did teachers preferring goals of the 1960s. Science teachers committed to modern goals were more likely to be teaching in middle school and attending more inservice workshops. The authors recommended that professional organizations convey the importance of contemporary goals to teachers through local seminars and workshops.

The West African Examination Council's (WAEC) policy and its impact on teaching chemistry in Nigerian secondary schools was studied and analyzed by **Alao and Gallagher**. Five public figures in Nigeria and Great Britain were interviewed concerning policy formulation and implementation, and five pertinent documents were analyzed. The interview data yielded information that compared the operation of WAEC in West Africa and Nigeria and the University of London School Examinations Board (ULSEB) in England. Two main differences were discerned: the influence of the African government on WAEC's operation, whereas, the ULSEB is not influenced by the British government; and, the issue of test security in African states. The authors reported the need for better communication within the Nigerian centralized educational system. Also mentioned was preservice training of chemistry teachers, especially in communicating up-to-date scientific information.

Marsick and Thornton surveyed chemistry teachers from the Washington, D.C. area to verify the need for safety instruction in the high schools. Responses were received from 37 of 101 high schools surveyed. The results indicated the following: passing a safety quiz is the most popular way of ensuring that students are familiar with safety rules and regulations; most schools have goggles and require that they be worn in chemistry laboratories; the majority of teachers follow school guidelines for ordering and storing chemicals; half of the teachers have been informed of proper chemical wastes disposal; personal injury in the chemistry laboratory had been reported in about three quarters of the schools, most of them minor burns; and, few teachers participated in inservice training that regularly stressed laboratory safety and health. The authors concluded that chemistry teachers need safety training and recommended that colleges offer courses in laboratory safety.

A random sample of college biology departments that offer post-baccalaureate degrees were surveyed by **Worth and Hanne** to identify departmental practices, anticipated changes in faculty curricular specialization, means to attract students, and self-evaluation practices. Responses (30% of 232 departments responded) revealed that departments across the schools sampled had relatively equal distributions of faculty expertise; most faculty were active researchers and half obtained off-campus support; about two-thirds of the departments anticipated expansion in molecular biology; most programs offered a non-degree course; and, most departments have undertaken self-study and found the process useful.

Wood analyzed the effect of state mandates on science instruction. Performance-based instruction was mandated and student scores monitored as one basis for accreditation. Participants in the study included 165 seventh grade science students and 4 teachers. Qualitative research methods provided information about the contextual nature of the classroom processes. Assertions generated during the field study were the following: teachers have redefined the goals of science instruction to increase the focus on acquisition of facts; teachers alter their usual instructional behavior to implement uniform instructional procedures; and, the teacher and student interaction constrains student opportunities to learn science. Wood concludes that state-mandated policy here seemed to have obstructed the intended results of improving science instruction.

1.23 What are some of the major research findings with implications for the future?

Preece reviewed the major research findings published during the last 10 years as a means of assessing progress toward a science of teaching science. Two broad principles emerged: the Qualitative Principle of Teaching (i.e., differences in teaching style have little effect on learning) and the Quantitative Principle of Teaching (i.e., more teaching leads to more learning). The author concluded that differences in pupils' characteristics account for major learning outcomes in science, generally divided in two categories, reasoning ability and prior knowledge. Also described is the Children's Learning in Science Project at Leeds University in which instructional materials were developed to aid science learning where pupil characteristics act as constraints.

Research on science education in the Caribbean in the years 1970-1987 was summarized by **Fraser-Abder**. The data base consisted of more than 300 papers from 17 Caribbean countries in the form of completed doctoral theses, published papers, conference and seminar papers, and university-based mimeographed research material. Results of the synthesis yielded the following themes or topics: agricultural education; assessment in science education; cognitive development and concept attainment; curriculum development, implementation and evaluation; environmental education; science achievement and orientation; science attitudes; nutrition and health education; science education and teaching, science teacher education, and scientific literacy.

Gunstone, White, and Fensham's historical review describes how past research centered around experiments designed to compare treatments on groups of students. Methods of instruction and student ability were the primary variables tested. Later, research focused on questions about individual learning, especially memory. Probing children's ideas about natural phenomena has become central. Simple definitions for learning have been replaced by complex ones. Involvement in curriculum development redirected teams of researchers to science classrooms where teachers and researchers worked as equals. Research and practice became cyclical. Operating within the classroom, researchers observed students constructing their own idiosyncratic meaning of science. Constructivist perspectives have prevailed within the belief systems of the leadership. The most recent era of research centers around the alternative science conceptions of learners. Analyzing the forces that directed the Monash University team over the last 20 years could be generalizable to other research groups.

Haig insists that meta-analysis is inappropriate for research in science education. The argument centers around the philosophic underpinnings of scientific versus evaluative inquiry in educational research. Haig challenges Glass' premise that evaluative inquiry via meta-analysis need not explain the causal mechanisms of the product or program under evaluation. Rather than function as an integrator of research findings, continues Haig, meta-analysis should serve as a data analytic procedure that generates theories, which in turn, brings forth questions requiring explanations.

Barnes and Conklin propose a three-step model that would allow science education researchers to make recommendations to teachers for improving classroom learning. In the first step, identify research findings that are pertinent to educational needs. Then researchers plan educational research based on comprehensive theory. Results here could lead to the third step, the outlining of classroom implications.

1.3 Issues in the Profession

1.31 In what ways can business influence practice?

Harty, Kloosterman, and Ault surveyed select business and industry employers (n = 18) to assess their beliefs about the mathematics and science needs of students who seek employment upon graduating from high school. Skills required for successful entry-level job performance but identified here as deficiencies include the following: slow or incorrect calculations in basic arithmetic; inability to measure; lack of proficiency in converting fractions, decimals, and percentages; and, inability to apply science process skills to solve on-the-job problems and make decisions. The employers also link ability to analyze, synthesize, and evaluate to upward mobility from entry-level positions.

Eltinge and Glass surveyed company representatives (n = 14) who support precollege science education through business and education partnerships. The results indicate that strengthening career education was the major reason for establishing partnerships. Prominent types of support provided by the businesses include sharing of company personnel, contributing financial support, and donating equipment and materials. Data further revealed that the initial contact for creating partnerships came from both within and outside of the businesses, but maintenance of a partnership usually came from within. Partnerships are viewed as an effective means of addressing personal, social, and career science goals.

1.32 What gender differences are related to teaching practices and career choices?

In pursuit of factors that may explain the underrepresentation of women in science, **Jones** probed student-teacher interactions, classroom atmosphere, and classroom behaviors. Subjects for the study, 30 physical science and 30 chemistry classes containing a total of 1332 students, were observed using the Brophy-Good Teacher-Child Dyatic Interactions System. Qualitative data on classroom atmosphere, class demonstrations, and teacher verbal patterns were also recorded. Data analyses revealed significant differences in teacher praise, unsolicited responses, procedural questions, and behavioral warnings based on student gender. Teacher and student gender and science subject and student gender interacted with the behavioral warning variable.. Male students were more likely to participate in science activities. Also, teachers were more prone to ask males to carry out science demonstrations. Teachers continue to stereotype science occupations and reinforce the role of the woman as homemaker.

Jones and Wheatley's literature review sought factors which affect female choices of science-oriented classes and careers. Reviewed were sociocultural factors, teacher influences, and student experiences. Factors that influence the entry of women into science over which educators have little control are innate ability, preschool experiences, and parental expectations. These factors are linked to several school-related variables that educators can influence. Teacher expectations, teacher-student interactions, augmented by appropriate role models and activities that develop personal independence and self-confidence, are recognized as school related influenceable factors that impact attitude toward science and science achievement. Science achievement is linked to science course selection that in turn affects career options. The authors encourage teachers and teacher educators to recognize their own biases of differential expectations for male and female students, and to assist females in developing personal characteristics associated with success in science.

1.4 Invited Commentary — Dorothy Gabel

From the viewpoint of the number of studies included in this chapter of the annual review of science education research reports, the major professional concern of science education researchers is the effectiveness of the use of technology in regard to both teachers and students. One wonders whether the number of studies stems from the many computer workshops that are being given for inservice teachers and/or the infusion of technology into the preservice curriculum. Both of these provide research populations that are convenient to study. Nevertheless, the results of the studies are providing valuable information about the effectiveness of the use of computers in science instruction. This is important in helping schools not only to decide whether or not to spend the vast sums of money that would be needed to equip schools with sufficient computers for effective computer usage, but also to help determine what types of computers and software should be purchased. No matter what the reason for the research, it appears that there is a growing body of evidence that the use of computers has potential for producing change in both teachers and students.

The use of computers by certified teachers can be increased by participation in workshops (Ellis and Kuerbis). At the preservice level, although prospective teachers did not learn more biology when computers were used in the course, their attitudes toward the use of computers became more positive (Lehman). This is certainly an important educational objective for preservice teachers. Rowland found that there was a differential effect for achievement and application for preservice teachers depending on whether computers were used for tutorials or simulation. Increased achievement was produced by tutorials whereas increased application of science concepts was produced by simulation. Shyu found that computers could also be used to practice classroom management techniques.

At the K-12 level, several studies showed creative use of the computer in determining the effectiveness of its use in improving instruction. A study by

Krajcik, Simmons, and Lunetta showed that the computer in conjunction with a VCR can be used as a tool to provide information about students' cognitive and affective behaviors. Wilson showed how the computer has the potential for enhancing learning by taking students' intuitive theories into account. Constant showed no difference in understanding motion concepts or the integrated process skills when simulations of amusement park activities were used to teach physics.

Two studies provide some information about the effectiveness of using MBL approaches in the teaching of science. Brasell found that students in physics had a lower error rate on velocity problems when using real time versus delayed time or paper and pencil approaches. Adams and Shrum showed that in a biology class when students collected and analyzed data using computers they became better at interpreting data whereas students using a conventional approach were better at constructing graphs. These findings are similar to those found in mathematics education on using calculators. Students appear to focus more on the meaning of the story problem or science data when they use an instructional aid that takes their focus off part of the task (arithmetic or graph construction). This points out the necessity for combining computer instruction with conventional instruction rather than using either one exclusively.

At the college level, studies centered on the use of computers in CAI and tutorial instruction. McCurry showed that there were no significant differences in the use of computers for drill and practice in a physics course. Mousa showed that there was a pretest-posttest gain in achievement in using a chemistry tutorial for balancing equations. Hauben and Lehman showed that chemistry problem solving achievement on volume and word problems was superior for students using a CAI program. For more complex retention problems, it was inferior.

In summary, the major emphasis in this chapter of the review is on studies about the use of technology in education. Although the time lag between when the research is done, published, and reviewed must be recognized, it is rather disappointing that more studies are not included on the use of newer technology such as videodiscs in both the K-16 classrooms and in preservice and inservice teacher preparation programs. It is encouraging, however, to see studies that give more detail about the effectiveness of computers in practice, particularly at the secondary science level. Data of this nature will be useful in encouraging teachers to use computers in their own classrooms as aids for improving concept acquisition and for other instructional objectives.

Another important area reviewed under Professional Concerns is the use of research by teachers in their own classrooms. Several studies indicate an interest in this area. A report by Blank indicates research interests of teachers and a study by Howe presents a model that can be used with teachers to promote the use of research in their classrooms. This is an important development because, over the years, several studies have been done to indicate the research interests of teachers, but little has been done to encourage the use of the research findings.

When research becomes important to teachers, there will be an increased need for research reviews. A report by Preece and one by Fraser-Abder will be useful in this regard. A report by Gunstone, White, and Fensham shows how present research tends to increase knowledge about why learning varies from the use of different strategies and may have more useful applications for teaching than in the past. Haig examines the rationale for meta-analysis, a technique commonly used to synthesize findings from a group of common studies.

Several other studies have investigated the goals of science education (McIntosh & Zeidler) or the effect of policy on practice (Alao & Gallagher; Wood; and Worth & Hanne). A more specific survey on safety in chemistry instruction was conducted by Marsick and Thornton. Research on policy is of utmost importance in science education today and will continue to become more important as the state and federal governments increase their role in demanding quality science education programs.

The final section of the Professional Concerns chapter considers two topics: (1) How businesses inform science education practice (Harty, Kloosterman, & Ault; and Eltinge) and (2) How gender differences affect achievement and career choice (Jones; and Jones & Wheatley). The former studies should become much more prominent as the demands of the marketplace increase and industry plays a larger role in supporting education (for example, through cost-sharing on NSF-funded projects). On the other hand, the lack of studies about gender differences is a real disappointment. It reflects the same trend over the past few years of the failure on the part of researchers and teachers to see the importance of this issue in increasing the number of women selecting science careers, and hence the strength of science education in this country.

2.0 Teacher Education

The reviews in this chapter address three broad areas: status of teacher education (14 studies), preservice teacher education (15 studies), and inservice teacher education (7 studies). Status studies stretched from colleges in New England to parochial schools in Texas, and on to Thailand, Malaysia, and Jordan. Other reviews range from the induction year for beginners to ways of wooing certified but non-teaching graduates back to classroom teaching. Preservice teacher education emphasized the efficacy of several teaching strategies and instructional packages. Summer institutes and related forms of staff development dominated research for inservice science teachers.

2.1 Status of Teacher Education

2.11 What is the status of teacher education in select regions of the U.S.?

Barrow gathered demographic data from 25 secondary science methods instructors (58.1% of those queried) in New England. Probed were their professional preparation, the content of their methods courses, length of teaching experience, and other professional activities. The typical secondary science methods instructor is male, enjoys senior faculty status, and has taught secondary science methods for more than 10 years. The respondents were also better trained in science than science education and most of them have taught secondary school science. The content of their courses varied considerably. High priority was granted to the nature of science, inquiry teaching, science processes, and classroom management. Low priority topics included concept mapping, new technologies, and content reading strategies. The respondents are minimally involved in sustained professional development of science teachers and few publish in professional journals or regularly attend conventions of the National Science Teachers Association, reports Barrow.

Computer files and certification records maintained by the Idaho State Department of Education were examined by **Heikkinen** to determine the academic qualifications of 436 Idaho secondary science teachers. The data revealed that only 57% of the State's secondary teachers are certified to teach the science subjects assigned to them and less than 25% of earth science and physics classes are taught by teachers certified to teach those subjects. Twenty-one percent of Idaho's seventh grade life science teachers and 16% of their high school physiology teachers are not science certified. Teachers of physiology are also least likely to have taken a science methods course. According to the authors, the findings present a more bleak picture of science teaching in Idaho than reported just a few years earlier.

In Texas, **Meissner** set out to systematically identify the science teaching needs and concerns of 341 teachers in a K-8 parochial setting. Over three-fourths of the teachers responded to a demographic questionnaire, the

Moore Assessment Profile (to identify needs), and the Stages of Concern Questionnaire. High priority needs were more effective use of instructional materials, improvement of instruction and planning, and a better understanding of students. The teaching concerns profile suggests that all of the respondents can best be described as non-users of the innovation, namely teaching science.

Melear compared the responses of scientists and science educators in Ohio and Georgia on a Likert-type survey regarding select facets of science education. In part, the two groups agreed that science teaching in college and secondary school were dissimilar. They disagreed on the enrollment of elementary education students and science majors in the same college science courses. Melear suggests areas where dialogue between the groups has the highest probability for success.

2.12 What is the status of teacher education in Jordan, Malaysia and Thailand?

Abu Bakar, Rubba, Tomera, and Zurub compared the perceived professional needs of 365 Jordanian and 1,162 Malaysian secondary teachers. Their Science Teacher Inventory of Need was juried by seven experts and tested by extensive factor analyses. The instrument tested seven categories of perceived needs. Jordanian teachers' needs fell into four of the seven possible categories: delivering science instruction, managing science instruction, administering instructional facilities and equipment, and self-improvement of teachers. The needs of Malaysian teachers included the above four plus delineating objectives of science instruction. The researchers report that the perceived needs of American science teachers are similar to those of Jordanian and Malaysian teachers.

Gan examined and assessed the contemporary status of environmental education in preservice science teacher education at Malaysian universities. The perceived curriculum needs of university science education programs were also sought through a survey of science educators, science teachers, and curricular planners. In general, secondary science teachers in Malaysia are inadequately prepared to teach environmental education. Based on the results of the survey, the researcher's perception of environmental education, and expert opinion gleaned from the literature, a set of curricular guidelines was written for teacher educators in Malaysia. The environmental curriculum is composed of three domains: knowledge, teaching skills, and attitudes.

In Thailand, **Purepong** studied the relationships of five affective attributes and teachers' self-concept of science ability. Thai preservice science teachers (n = 222) were also compared to Thai non-science preservice teachers (n = 238). Significant positive correlations were found between self-concept of science ability and two attitude objects: science and the teaching of science. On the other hand, the correlation of attitudes toward science and locus of control, pupil control ideology, and open-closed mindedness were negative. Preservice science teachers express a significantly higher self-concept of science ability than do non-science teachers.

2.13 What factors facilitate classroom teachers as educational innovators?

Shroyer analyzed the impact of four factors on school leaders who sought to improve science teaching: community, organizational, professional and procedural factors. Fourteen science teachers from rural and/or small school districts in Kansas were trained to implement a science improvement project in their respective districts. Surveys, interviews, site visitations, and census data were collected on each of the fourteen participants, their schools, and communities. Assessed was the degree and level of implementation at each site. Repeatedly identified as critical to implementation Shroyer reports the following: diversity of groups and persons involved; congruency between the innovation and the groups and individuals involved; pressure for change; the wherewithal to focus the pressure upon school improvement; and, access to information, support, and resources.

2.14 What school reforms would entice certified but non-teaching graduates back to the classroom?

T. H. Williams surveyed 122 teachers who had completed science and/or math certification requirements at Virginia Tech between 1980 and 1986 to determine employment status. If not currently teaching, respondents were asked to specify teaching conditions that would encourage them to return to or enter teaching. Three groups of subjects were queried: current teachers, those who left teaching, and those who chose not to enter teaching. No significant difference was found among the three groups in regard to their opinions of work satisfaction in the classroom. Some teachers left the classroom to raise a family. Others left due to lack of administrative support, poor student discipline, and low salaries. Almost 60% of the non-teachers in the sample would enter or reenter teaching if offered a suitable position. Their return would necessitate better discipline among students, smaller classes, improvement of the physical environment, the removal of incompetent teachers, and the reduction of teacher isolation and stress.

2.15 What academic factors complement the teaching of evolution?

Roelfs probed the relationship of select academic factors and teachers' emphases on evolution and their veracity of instruction. He surveyed 673 middle school, junior high, and senior high school teachers from Arkansas and Missouri and interviewed a much smaller sample from the two states. The factors selected were academic background in and content accuracy on the topic of evolution, degrees, credit hours earned in biology, teacher discrimination between science and technology, and classroom resources. The teachers' emphases on evolution and instructional accuracy were related to degree level, credit hours in biology, and stress on evolution in the teachers' academic background. Teacher accuracy was also related to the choice of teaching evolution as both theory and fact. The ability to discriminate scientific from teleological explanations was related to a teacher's knowledge of the role of theory in science. According to Roelfs, 65 percent teach evolution as a theory, 8 percent teach it as theory and fact, and 31 percent balance evolution with alternative explanations.

2.16 How highly do school administrators rate teachers?

By telephone **Kloosterman, Harty, and Woods** surveyed a stratified random sample of 20 Indiana secondary school administrators to ascertain their beliefs about the quality of science and mathematics instruction received by students. Teachers' content knowledge and their ability to communicate that knowledge to students were the foci of the study. Their responses revealed a satisfaction with the knowledge background of their science and mathematics teachers; they were only moderately positive toward the teachers' ability to communicate knowledge. In response to a question about ways to improve teachers' knowledge, the administrators supported inservice programs, college coursework, and participation in professional organizations. Observing model teachers was the suggestion most frequently offered by the administrators when quizzed about improving teachers' communication skills. In this study, school administrators were on the sidelines assessing teacher performance.

In another study on the quality of science instruction, **Prather and Field** conclude that administrators must be directly involved in staff development for it to be effective. They recommend that instructional and administrative skills be developed simultaneously through the joint training of teachers, principals, and supervisors.

2.17 How important are induction programs to beginning teachers?

Sanford's review of the literature revealed that the challenges facing beginning science teachers emanate from the nature of the science curriculum, the frequent mismatch between teaching assignments and beginning teachers' science specialization and their preservice field experience, and the lack of rewards for department heads and veteran teachers who help new teachers. Sanford advises administrators to assign beginning teachers to courses for which they have sufficient preparation; to limit the number of different course preparations expected of the beginning teacher; to provide assistance to the beginning teacher in the areas of instructional planning and classroom management; and to provide incentives for them to participate in structured interactions with supervisors, staff developers, and other teachers.

2.18 How well do science majors planning to teach compare to their non-teaching counterparts?

Tolman, Baird, and Haderlie appraised the quality of graduating secondary science education majors at Brigham Young University. Compared were science teaching majors and their non-teaching counterparts on the variables of exit grade point average (GPA), natural science American College Testing (ACT) score, and composite ACT score. Overall, the findings revealed that science teaching majors are equivalent or superior to their non-teaching counterparts on the three measurements. Comparisons between subpopulations of science teaching majors who graduated during the period of 1970-1975 and 1979-1984 also revealed no significant differences on the three variables. The authors concluded that the quality of BYU science teaching majors has remained relatively high when compared with nationally reported trends.

2.2 Preservice Teacher Education

2.21 How do select teaching strategies and instructional packages affect teaching effectiveness?

O'Non probed the effects of instructor modeling on the attitudes, knowledge, and skills of preservice elementary teachers enrolled in a physical science course. In a hands-on laboratory approach, staff members role played effective science teaching with the expectation that preservice teachers would adopt and model their exemplary teaching practices. The effect of the instructional package was tested by a blend of experimental- and ethno-methodology. Science anxiety decreased; science enjoyment increased. The understanding and application of knowledge increased and teaching skills improved. According to O'Non, the study supports courses that integrate instructional modeling, provide opportunity for active skill development, and supervise the practice-teaching of preservice teachers.

In Thailand, **Wacharayothin's** instructional package was an intensive eight-week training regimen on higher level questioning in conjunction with wait-time applied within a microteaching experience. Twelve teachers randomly were assigned to either experimental treatment or control. Significant group differences were disclosed in use of wait-time and the number of recall and higher level questions asked, with the results favoring the treatment group. The chemistry achievement scores of the students involved in the two treatments were not significantly different.

In Nigeria, **Akindehin** tested the effect of a nine-unit, instructional package — the Introductory Science Teachers Education (ISTE) program — on 145 Nigerian preservice science teachers' understanding of the nature of science and science-related attitudes. The ISTE, a package of lectures, group discussions, and laboratory experiences, was presented to the experimental subjects in addition to a traditional teacher education program. Three scales well developed in the literature served as measures of the dependent variables. The subjects exposed to the ISTE program acquired a better understanding of the nature of science and more favorable science-related attitudes than did those not involved in the instructional package.

Does reading science content affect attitudes toward science and the teaching of science? In **Inman's** study, preservice elementary teachers were assigned to one of three treatments: six readings in science methods, none in science content; six readings in science content, none in science methods; and three readings in each area. Subjects were tested on attitudes and knowledge before and after treatment. They also responded to a questionnaire that yielded demographic data plus their perceptions of the readings, perceptions of their own attitudes, and instructor credibility. Inman reported a significant relationship between the students' perceived usefulness of the readings and their attitude toward the teaching of science. No significant correlations were disclosed between science attitudes and the other variables tested, including the reading of science content.

Baird and Koballa explored the effect of computer instruction and group size on preservice teachers' acquisition of skills in forming and testing hypotheses. The results of the study showed strong aptitude-treatment interactions between group size and mode of presentation, and initial hypothesizing and reasoning skills. More importantly, individuals who participated in cooperative learning groups rated their experience as more successful and the computer programs as more useful than did individuals working alone.

Barman assessed the efficacy of selected instructional materials to prepare 48 elementary education majors to teach science. Three objectives were identified: developing a working definition of science and the scientific enterprise, posing effective questions in the classroom, and applying the learning cycle to classroom instruction. Significant gains were made between pretest and posttest.

Stepans, Dyche, and Beiswenger compared the effect of two different teaching models on 52 preservice elementary teachers' understanding of the sinking/floating action of objects phenomenon. The subjects experienced either an expository teaching model, consisting of lecture, demonstration, and recitation, or the learning cycle model. Pretest and posttest data were collected via one-on-one interviews. The authors conclude that both groups gained in their understanding of the concepts, with the learning cycle group having an edge over the expository group.

The instructional strategies used by science teachers are considered to be a product of their conceptions of science teaching. Using constructivism as a backdrop, **Hewson and Hewson** (a) argue for the adoption of conceptual change as the appropriate conception of science teaching. They conclude that inservice and preservice science teachers should be presented with this and other views of teaching so that they may develop their own conceptions of science teaching.

2.22 How effective is the integrated professional semester?

Scharmann (a) assessed the influence of three differently-sequenced instructional models and locus of control on preservice elementary teachers' understanding of the nature of science. The three instructional models tested were: science content courses followed by a science methods course; science process instruction followed by science content and science methods courses; and science process instruction followed by three semesters of integrated science content/science methods/field experience. The literature regards the integrated model as superior. Also tested was variation in content, logical thinking, achievement, and quantitative and verbal aptitude. The effectiveness of the treatments was measured with four instruments that are well established in the literature, along with achievement test scores and quantitative and verbal aptitude scores that were a part of subjects' records. The second instructional model, a strategy where process, content and teaching methods were taught separately, predicted student understanding of the nature of science. Locus of control scores did not influence significantly the subjects' understanding of the nature of science.

Lehman and McDonald tested the effect of an integrated professional semester on preservice teachers' beliefs about integrating science and mathematics. They also compared the beliefs held by preservice teachers with those held by practicing science and mathematics teachers. A ten-item Likert-type scale measured changes in belief. Pronounced shifts in the beliefs of 24 student teachers manifested a heightened awareness of instructional material that facilitates integration, and agreement with the position that integration is a preferable method for teaching the two subjects. The 98 practicing science and mathematics teachers also preferred integration of the two subjects. Fewer mathematics teachers than science teachers practice integrating science with math. Time constraints and their weak background in the sciences hampered integration.

2.23 Does locus of control influence teacher education?

Scharmann (b) examined the power of six variables to predict the ability of 127 preservice elementary teachers to develop an understanding of the nature of science. The predictor variables included logical thinking ability, science content knowledge, academic achievement, science achievement, and verbal and quantitative aptitude. For subjects classified as internal on a measure of locus of control, all six of the variables were found to be statistically significant in predicting an understanding of the nature of science. The combination of variables accounted for 23% of the variance, with logical thinking accounting for 16%. In comparison, none of the variables were statistically significant in predicting an understanding of the nature of science for external subjects, reports Scharmann.

Convinced of a strong link between locus of control and attitude, **Haury** attempted to modify the control orientation of prospective elementary teachers through instruction. The quasi-experiment was integrated into a science methods course, and it involved 98 students during two academic quarters. Two instructional treatments incorporating strategies shown to have positive effects on attitudes toward teaching science were devised. Techniques designed to shift one's locus of control orientation toward internality were embedded in the experimental treatment, but absent from the control treatment; they emphasized self-management, goal clarification, and individualized course expectations. The results revealed a significant difference in science locus of control orientation between groups following treatment, with students in the experimental group displaying greater internality.

2.24 Do sign-language lessons for biology students influence the teaching effectiveness of deaf student teachers?

Kinney assessed the effect of sign-language lessons taught by a deaf student teacher on the achievement and attitude scores of ninth grade biology students. The student teacher was assisted by an interpreter; the students possessed normal hearing. The findings of the eight-week study revealed that students with normal hearing are likely to benefit from sign-language training if it is presented in a way that enhances their interaction with the subject matter. Such lessons may improve personal relationships more than achievement, Kinney concludes.

2.25 What instruments are under development for preservice teachers?

Assuming that teacher perceptions about science content and students will influence their instructional practices, **Hewson and Hewson** (b) designed an instrument to identify teachers' conceptions about science teaching. Central to the instrument were six broad categories dealing with science teaching: the nature of science teaching, learning, learner characteristics, rationale for instruction, preferred instructional techniques, and conception of teaching science. Validation of the instrument involved the interview of four subjects representative of the group for which the scale was designed.

The Stages of Concerns Questionnaire is an instrument that assesses inservice teachers' concerns about educational reform and innovations. **O'Sullivan and Zielinski** set out to establish the validity and reliability of a modified version of the instrument for preservice teachers enrolled in undergraduate and fifth-year teacher education programs. They concluded that their modified version can be used with confidence to assess the professional concerns of preservice teachers.

2.3 Inservice Teacher Education

2.31 What is the impact of summer institutes and other strategies on staff development?

Lawrenz and McCreath (a) employed quantitative and qualitative methods to assess and compare two inservice science programs. The programs followed the National Science Foundation (NSF) master teacher model where select teachers attend three-week summer institutes with the understanding that they will return to direct inservice training locally. The first group of 19 master teachers, most of whom taught at the elementary and junior high school levels, was drawn from across the State of Arizona. They were trained in both methods and content, and each teacher designed his/her own course outline for the upcoming inservice course. The second group of 21 subjects were secondary teachers from a major metropolitan area. Their training was primarily in science teaching methods, with emphasis on the learning cycle, and they designed one common inservice course outline. Returning to their school districts the two groups of master teachers taught 763 teachers, most of them elementary teachers, in evening inservice science courses. Physical science concepts were taught, and a hands-on, laboratory method was emphasized. Local teachers were tested in science content, science attitude, and science beliefs. Students of these teachers also responded to attitude scales and science content tests. The instruments were well established tests drawn from the literature. Qualitative instruments were observation schedules, interviews, and a questionnaire. Qualitative data revealed important differences in the two programs which reflected the difference in the characteristics and training of the two groups of master teachers. Quantitative data revealed no group differences in teacher attitudes and beliefs, but qualitative findings suggested better attitudes among those taught by the first group of teachers. The authors concluded that qualifiable data are a valuable source of potentially-relevant variables. Quantitative data documents the degree of effect afforded by treatment.

Similarly, **Ofelt** tested the effect of a NSF summer institute on the needs, skills, and attitudes of the teachers who participated, as well as the attitudes and self-concept of their secondary school students. There was a pretest-posttest difference in the scientific attitude scores of students. Scientific attitudes and teacher self-actualization were related. Distinct variables discerned student from teacher groups. There were no significant changes in the teachers' needs as a result of the NSF institute. However, when extrapolated to a larger sample, the researcher concluded that NSF institutes are effective in decreasing teacher needs.

Structured within a two-week Institute for Chemical Education workshop, **O'Brien** analyzed the effect of a short term, intensive, and skills-oriented inservice model on teachers' improvement. The instruction of 22 elementary, middle school, and high school teachers focused on teacher demonstrations as an instructional strategy. Teachers read accounts of chemical demonstrations, observed demonstrations modeled for them, practiced, and received feedback. They taught middle school students. O'Brien also explored the applicability of the Stages of Concern Questionnaire for assessing the merits of the workshop. Data gathered before the workshop, immediately thereafter, and four months later, suggested that the brief and intensified workshop eased participants from low-level self concerns to higher level impact concerns. The institute motivated participants to provide inservice leadership in their local schools. Here the results contradict the findings of prior concerns-based studies that endorse the need for a year or more of multiple inservice experiences to shift teachers from the level of self concerns to impact concerns, according to O'Brien.

Wier studied how a four-week institute might minimize the obstacles to science teaching among primary grade teachers. The obstacles chronicled by teachers in pre-institute interviews were the lack of time, materials, equipment, and support personnel and the lack of teacher knowledge, skills, and confidence. At the summer institute 10 primary teachers learned science content, and they wrote, taught, and revised a unit on light and shadows. Teachers were then obliged to teach the unit in their classrooms the following year under the direction of the institute supervisor. Teachers' logs, final reports, and interviews documented an improvement in science teaching, especially in teaching methods and classroom management. Strategies learned during the institute transferred to subjects outside the science curriculum.

Macdonald and Rogan compared the teaching behavior of teachers trained in the use of Science Education Project materials to the behavior of teachers following a traditional curriculum. Eighteen junior secondary teachers in the Ciskei, a rural region of South Africa, half of whom had received the training, participated in the study. Data collected using the Science Teaching Observation Schedule indicate that the teachers asked higher order questions and more often engaged their pupils in practical activities than did those following the traditional curriculum.

2.32 Does computer conferencing facilitate staff development?

Kimmel, Kerr, and O'Shea designed an inservice model to increase the opportunities for teacher interaction as well as avail them to pertinent instructional resources. The model included three components: teacher workshops, visits by university faculty to the participants' schools, and computer-mediated communications, facilitated by the Electron Information Exchange System (EIES). The EIES was the primary means for implementing workshop learnings, and the EIES facilitated teacher communication. Data collected from conference traffic analysis recorded teacher participation in the computer conferencing system. Membership in the conference increased from 29 to 52 teachers from November 1984 to November 1986; however, only a third of the members actively contributed to the system during this time. The percentage of teachers who read the comments sent to them over the EIES increased during the same two year period. In November 1986 about 70% of the teachers had read at least 80% of the comments as compared to 30% in November 1984. Overall, trends in the data show that usage of the EIES and workshop materials increased as teachers became more comfortable communicating via this technology.

2.33 Are teachers with limited knowledge prone to restrain classroom discourse?

Carlsen probed the relationship between teachers' level of science knowledge and discourse in their classroom. Four beginning biology teachers served as subjects for the study. Knowledge was examined at three levels: the curriculum, the lesson, and classroom utterances. Employing card-sorting tasks, interviews, and analyses of undergraduate transcripts, teacher knowledge was assessed. Computer software was designed that would model real-time discourses, code teachers' questions, and graphically display teachers' discourse. Classroom discourse and teacher knowledge were related at all three levels. Teachers with limited knowledge of a topic were prone to discourage student discourse, and they discouraged student questioning. The frequency of teacher questioning rose on topics about which they had little knowledge, reports Carlsen.

2.4 Invited Commentary — David P. Butts

Is it possible that what students know and believe is influenced by what their teachers know and believe? Is it also possible that what teachers know and believe is influenced by their formal schooling experiences, both preservice and inservice?

If so, the key challenge in science teacher education research is to determine what knowledges are related to which practices and attitudes: how strong are these linkages and why do these linkages exist?

In reflecting on this review of 36 research studies about the education of teachers, numerous pieces or variables that may be part of a large scheme are explored or manipulated to show that they exist or to describe the strength of their existence. But what is needed in this research is a bigger picture that makes interpretations of these studies possible. They are like a bag of pearls or a box of jigsaw puzzle pieces but missing is a diagram showing how the pearls should be strung or a cover picture showing what the total puzzle is like.

Underlying these studies in teacher education is an implied chain of beliefs—what teachers know influences what they do; what teachers do influences the success of their students; and, when students experience success, teachers feel good about it. Clearly operational definitions of the key variables are needed. What is meant by "knowledge," "practice," and "attitudes"?

Given a conceptual base or logic for this knowledge-practice-attitude domain of teacher education, there are three kinds of investigations that can help fill in the picture or can provide evidence to support the substance of the assumptions.

First, studies are needed to explore or seek evidence that indeed the variables of knowledge, practice, and attitudes can be observed. In the 36 studies included in this review, ample evidence of these variables is presented. Among the studies that observed knowledge the following results were identified:

- Science teachers have had different content courses. (Barrow; Heikkinen; Melear; Gan)
- Administrators believe that science teachers differ in their knowledge of science. (Kloosterman, Harty & Woods)
- Teaching models can increase a teacher's knowledge of science. (Stepans, Dyche & Beiswenger)

Studies that observed practice contained the following conclusions:

- Teaching experience is an indicator of practice. (Barrow; Lehman & McDonald)
- Teacher certification is an indicator of practice. (Heikkinen)
- Cooperative learning groups influence classroom practice. (Baird & Koballa)

Studies that examined teacher attitudes noted the following outcomes:

- Teachers have different priorities or concerns. (Barrow; Meissner; Abu Bakar, Rubba, Tomera & Zurub; O'Sullivan & Zielinski)
- Teachers' self-concepts influence teachers' attitude. (Akindehin)
- The integrated semester influences teachers' beliefs about science. (Lehman & McDonald)
- Self-actualized teachers have a better attitude about science. (Ofelt)
- Short term instruction can influence teachers' concerns. (O'Brien)

Second, demonstration studies show how these variables may be linked through evidence of differences when the knowledge, practice, or attitudes are present or absent. In the 36 studies contained in this review, evidence of these linkages has been demonstrated. Several studies documented the linkage between knowledge and practice and offered the following observations:

- If there is a congruence between the goals of schools and the science curriculum, it will be used. (Shroyer)
- If resources to use a curriculum are available, the curriculum will be used. (Shroyer)
- If teachers know the content (evolution), they will teach it in the classroom. (Roelfs)

- If teachers observe a model teacher, their practice will change. (Kloosterman, Harty & Woods; O'Non)
- Observations by trained administrators help teachers change their practice. (Prather & Field)
- If teachers are assigned to teach what they know, their induction will be successful. (Sanford)
- If teachers experience specific skills training, their practice will change. (Wacharayothin; Hewson & Hewson; Carlson; Wier)
- If teachers know science, they will be more successful in integrating science and mathematics. (Lehman & McDonald)

Additional studies revealed a linkage between knowledge and attitude and contained the following results:

- If new teachers are assisted in instructional planning, they will have an improved induction attitude. (Sanford)
- If teachers observe a model teacher, their attitude toward teaching science will improve. (O'Non)
- If science resource materials are useful, teachers' attitudes will be positive. (Inman)
- If teachers have access to instructional strategies knowledge, their locus of control will change. (Haury)

Linkages were also shown to exist between practice and attitudes with the following conclusions reached:

- School expectations of practice influence use of a new curriculum. (Shroyer)
- Student discipline and the physical environment can influence the decision to return to teaching. (Williams)
- Reduction of stress can influence the decision to return to teaching. (Williams)
- If teachers have a limit to the number of new courses they must teach, their induction will be improved. (Sanford)
- If teachers have access to appropriate instructional models, their attitude will improve. (O'Non)
- If teachers use sign-language with students, the students' attitudes will improve. (Kinney)
- If teachers experience a Master Teacher Model in a short institute, attitudes will improve. (Lawrenz & McCreath)

Third, experimental studies are undertaken to generate greater understanding of why teachers' knowledge, practice, and attitudes are linked. These studies are based on theoretical constructs that are thought to exist and are supported by empirical evidence. In the 36 studies reviewed, no evidence of the theoretical linkages were seen. Thus from the studies summarized in this review, we do know the following about teacher education:

1. teachers have different knowledge bases in science;
2. teachers who know more science tend to teach more science and tend to feel better about it; and
3. teachers who know more science tend to use more of that knowledge in their classroom (and thus give their students greater access to science ideas?).

A missing but key element in these studies presents a challenge for future researchers. Why do these trends exist? What theoretical basis explains why teachers' knowledge is linked to their practice and attitudes? Implied in some of the studies is the possibility that the manner in which teachers were exposed to their knowledge may be at least as important as the knowledge they acquire. Methods of instructing teachers in their preparation programs may influence their delivery of instruction and management of students as much as the knowledge that teachers have acquired. These same methods of instructing teachers may also influence the success of teachers' practice.

Thus, looking ahead in science teacher education research, there is need for research studies that synthesize what is known and from the unknowns in that synthesis generate questions for future investigators to explore.

3.0 Programs

The studies reviewed in this chapter cover four general areas: the status of programs (7 studies), perceptions of programs (5 studies), program evaluation (4 studies), and programs identified as exemplary (11 studies). Studies within the status section focus on science education in selected states and regions of the United States and African nations, as well as the status of earth science education and energy education. Within the perceptions section, studies center on the perceptions held by civic groups, school administrators, and students. Program evaluation studies highlight the comparison of process-oriented and textbook-based curricula and assess the cognitive demands of Alternative Nuffield Physics. The attributes of exemplary programs and the characteristics of teachers associated with these programs are topics included in the final section.

3.1 Status of Programs

3.11 What is the status of programs in selected states and regions of the United States?

To collect information on the status of elementary science in the public schools of New Hampshire, **Hendry** surveyed elementary school principals (62%) across the State and conducted in-depth interviews and observations at six elementary schools. Data collected were compared with the desired state of elementary science education as prescribed by the National Science Teachers Association's Project for Promoting Science Among Elementary School Principals. Discrepancies between the existing state of elementary science education and the desired state were found in the areas of teacher content and pedagogical preparation, funding for science teaching materials and textbooks, and lack of time for teachers to teach hands-on science.

Lawrenz and McCreath (b) collected data describing the status of science and mathematics education in schools serving predominantly Native Americans in the Southwest. The responses of 82 teachers to mailed surveys, that were corroborated by several on-site visits, revealed that teachers were well educated, highly experienced, and open to curricular innovation. Mathematics instruction was a priority in the curricular reform, and some attention was given to hands-on experiences in science instruction. When compared to other schools in the Southwest, three differences were found: less diversity in the science and mathematics curricula, higher rate of teacher turnover, and limited communication between and within schools. These differences may influence students' lack of enduring interest in science and mathematics, according to Lawrenz and McCreath.

To assess the status of the science instruction in the elementary schools of the Wisconsin Evangelical Lutheran Synod, **Klockziem** surveyed 203 teachers. A questionnaire developed by Iris Weiss for the national assessment of science and an attitude measure developed by Moore and Sutman were the instruments. When compared to the results of the national assessment, science instruction assessed in this survey was inadequate. The emphasis given to science in the primary grades is on the decline; many schools lack equipment needed to teach science; the time devoted to instruction was below the national norm; and, the teachers' attitudes toward science were much lower than those held by exemplary teachers identified by the National Science Teachers Association. The teachers attributed the state of instruction to their inadequate preparation and need for assistance in using manipulative materials and innovative teaching techniques. According to Klockziem, the findings paint a bleak picture of science instruction in the Wisconsin Evangelical Lutheran Synod.

3.12 What is the status of programs in African nations?

Mawande surveyed school officials from ministeries of education and principals of teacher training institutions in Botswana, Malawi, Zambia, and Zimbabwe to assess the status of science education and science needs in the respective nations. The results revealed that the nations offered either nature study or general science in the primary schools; general science, integrated science, physical science or biology in lower and middle secondary schools; and, separate offerings in biology, chemistry, and physics in upper secondary schools. All schools lacked adequate facilities, equipment, and materials for investigations in science, with secondary schools better equipped than primary schools. Science education in these nations, the data revealed, tends to stress learning outcomes on the lower levels of Bloom's taxonomy of the cognitive domain, and it is failing to meet the national manpower needs for technicians, science teachers, and scientists. The findings provide a database which other developing nations can use to assess the effectiveness of their science education programs.

3.13 What is the status of earth science programs?

To assess the status of earth science education in Kansas schools, **Finson and Enochs** mailed surveys to 347 individuals identified by the Kansas State Department of Education as earth science and/or middle school science teachers. The findings, based on surveys completed by 289 teachers, revealed that the sample of earth science teachers is predominantly male, averaging from 36 to 40 years of age, and most have completed nine or fewer semester hours in the earth sciences. About half of those teaching earth science hold earth science certification. The courses taught by the teachers are predominantly textbook driven, with Merrill's Focus on Earth Science ranking first among the teachers sampled. Most earth science courses are taught at the eighth grade level with few districts requiring earth science at the high school level. The authors concluded that the findings are fairly consistent with those reported in the 1980 Science Education Databook.

In a status study of earth science programs in Iowa, **Hoff, Lancaster, Little, and Thompson** compared the data collected from earth science teachers in 1976 with those collected in 1986. In grade level offerings, gender, age, and science background, the findings for both samples mirrored those of Finson and Enochs' survey. The majority of earth science teachers also use textbooks to direct instruction, with Merrill's Focus on Earth Science the text most favored by teachers in the 1986 sample. The most disturbing finding, according to the authors, was the more than 20% decline in the time devoted to activity-based teaching between 1976 and 1986.

3.14 What is the status of energy education?

Vlahov and Treagust surveyed 333 Western Australian high school students to assess their knowledge of energy and attitudes toward energy conservation. The instrument measured facts and conceptual knowledge about energy and energy conservation. The 20-item, Likert-type attitude scale included three subscales (egocentric, sociocentric, and action-centered). The survey results suggest that males are slightly more knowledgeable about matters of energy and they hold more positive attitudes toward energy conservation than do females.

3.2 Perceptions of Programs

3.21 What perceptions are held by the public regarding public school programs?

At the request of **Yager and Penick**, 15 science educators from across the country distributed a one-page survey to members of service clubs and community groups in the years 1976, 1980, 1984, and 1986 asking their opinions on the relative importance of the four goals identified by the Project Synthesis research team: science affecting daily living, science for resolving societal issues, career awareness in science, and science necessary for further study. The results revealed the importance of science as preparation for further study to be the most important goal between 1976 and 1986. Perceptions regarding the importance of science for meeting the other three goals were elevated considerably during this ten year period. The favorable shifts in public perceptions concerning the importance of studying science in schools, according to the authors, conveys community interest in features of schooling beyond basic academic preparation.

Harty, Kloosterman, and Matkin surveyed 252 school administrators to assess their perceived needs of Indiana elementary and middle schools in science and mathematics. At both the elementary and middle school levels, the greatest need is instructional materials and equipment to teach science and mathematics. The assistance needed for gifted and talented students ranked second. Least assistance is needed in preparing programs for minorities, women, and the handicapped. A follow-up telephone survey of twenty administrators randomly selected from the original sample confirmed laboratory equipment as the greatest need, with computer hardware and software also identified as major needs.

Using a modified version of an instrument prepared by the National Assessment of Education Progress, **Hidayat** assessed the perceptions of

Indonesian elementary and secondary students (n = 1713) toward science classes, science teachers, the role of the scientist, and the usefulness of science. Here science is viewed as fun, exciting, and a subject that makes students curious. Science teachers are perceived as knowledgeable about science. These perceptions waned as students move from grade to grade at the same time that student perceptions of scientists become more favorable.

Prompted by the personal observation that Kenyan A-level chemistry students find organic chemistry more difficult than either inorganic or physical chemistry, **Brooks** constructed and administered a questionnaire to determine if the observation matched that of students. The scale followed a Likert format, with a final section where students could cite the level of ease or difficulty they experienced while studying organic chemistry. The sample consisted of students in their final year of A-level study in high school (n = 241), university students studying science (n = 23), college students training in either eduction, medicine, or agriculture (n = 32), and teachers of A-level chemistry (n = 16). Also, the teachers were asked to predict their students' responses. Organic chemistry was identified as most difficult by secondary and college students and the teachers, whereas the university students considered inorganic chemistry most difficult. Shapes of molecules, laboratory preparation of organic compounds, reaction mechanisms, differentiating between reaction conditions and reagents, industrial processes involving organic chemistry, and explanations of properties and reactions of organic compounds were the course topics identified as difficult by more than fifty percent of the sample.

3.22 What factors other than programs affect students' perceptions of science?

Charron probed student understandings of science in a rural community in the southeastern United States. In addition to precollege students, data sources included administrators, parents, teachers, and other community members. Data were collected by observation, interview, inventory and document analysis. Prominent among the findings of the study was the striking change in students' perceptions of the nature of science, the content of science, methods of learning and practicing science, and the value of science during the pre-college years. Many of the changes in student perceptions were viewed as impediments to the development of a scientifically literate citizenry. Factors considered to be responsible for the changes, aside from science programs, include parent and community mores. Charron concluded that further study of youths' perceptions of science is warranted because they reflect shared local culture and impact classroom performance.

3.3 Program Evaluation

3.31 How do process-oriented and textbook-based curricula compare?

Kyle, Bonnstetter, and Gadsden compared the science attitudes of elementary students (n = 228) and teachers (n = 44) involved in their first year of a new K-6 Science Through Discovery curriculum in Richardson Independent School District in Texas, with counterparts who experienced a textbook-oriented science curriculum. The focus of the new curriculum was the Science Curriculum Improvement Study (SCIIS). Data were collected near the end of the 1984 school year using the teacher and student versions of the Preferences and Understandings scale. Both scales include questions related to eight common scientific terms and 32 attitudinal items drawn from The Third National Assessment of Science of the National Assessment of Educational Progress. Students who experienced the discovery-oriented, process-approach curriculum held more positive attitudes toward science than did their counterparts. Significant differences were reported by the authors including the following: views of science as fun, exciting, and interesting; desire to spend more time in science; and, feelings that science is useful in both daily life and in the future. Furthermore, students in the experimental group performed as well on the eight content questions as did students taught science emphasizing the textbook. The finding that teachers representing both treatments possessed similar and somewhat negative attitudes toward science was disappointing, report the authors, particularly since the experimental teachers received extensive inservice education on the attributes of inquiry-oriented, process science.

In another study of the Science Through Discovery curriculum in Richardson Independent School District in Texas, **Kyle, Bonnstetter, Gadsden, and Shymansky** assessed the second year of the program. Observations of 68 science classes augmented the attitudinal data collected from students (n = 675) in grades 2-6 using the Preferences and Understandings scale. Attitudinal assessment mirrored those of the first year's evaluation; students in classes that used SCIIS held more positive attitudes toward science than did students enrolled in classes following a textbook-oriented curriculum. The observational data led to the following conclusions: students in classes using the SCIIS program were more actively involved in the study of science than were students in non-SCIIS classes; females were more actively engaged than were males in the SCIIS classes; and, SCIIS teachers used manipulatives in their teaching more often than did non-SCIIS teachers. The findings support use of a discovery-oriented, process-approach curriculum in the elementary grades.

Noraas surveyed and interviewed elementary teachers' in Oregon regarding their beliefs about the SCIIS program three years after its adoption in their school district. Strengths of SCIIS included the following: hands-on, process approach; the availability of a resource biologist; and high student interest. Time demands, an inadequate teacher's guide, and repetition of topics were identified as major weaknesses. The interviews revealed that teachers were familiar with the goals of SCIIS and their role as instructional leaders, but they held numerous misconceptions regarding the use of the learning cycle. Minimal inservice beyond the program's introduction was touted by the teachers as the primary explanation for partial implementation.

3.32 What are the cognitive demands of Alternative Nuffield Physics?

In considering the possibility that some of the topics in the Alternative Nuffield Physics course are too difficult for the average student, **Bounds and Nicholls** analyzed the cognitive demands of a number of physics questions taken from the Certificate of Secondary Education examination. They also assessed the compatibility of the Alternative Nuffield Physics assessment criteria with the Nuffield philosophy. Consistent with the Nuffield philosophy is the approval of the practical student work, work that emphasizes experimentation over routine verification. The results revealed that students performed more poorly on questions demanding abstract reasoning than on those requiring recall of definitions or the substitution of numbers into a formula. Moreover, it was found that the Alternative Nuffield Physics assessment criteria seem to conflict with the spirit of the Nuffield program and the role initially designated for experimentation. Designed as a physicist's physics course, Bounds and Nicholls question how much Nuffield physics can be modified for a wider audience without losing its essential character.

3.4 Exemplary Programs and Their Attributes

3.41 What attributes are common to programs identified as exemplary?

At the middle and junior high school levels, **Brunkhorst** gathered and analyzed data on teacher characteristics and student learning outcomes in three domains of science education, namely, knowledge, attitudes, and applications. Student knowledge was assessed by The Iowa Test of Basic Skills (Science Supplement), and items from the National Assessment of Educational Progress provided student attitude and application data. The findings disclosed that teachers of exemplary middle and junior high school science programs are highly experienced, view themselves as well qualified, use professional journals as resources, make presentations at professional meetings, use a variety of teaching strategies, and consider other teachers their greatest professional resource. Students in the exemplary middle and junior high school program held favorable attitudes toward science and science classes, and they scored well above the national norm on a standardized test of science knowledge. Only in the application domain did students of exemplary teachers fail to out-perform students in general.

In one of a series of case studies conducted as part of the Australian Exemplary Practices in Science and Mathematics Education Project, **Tobin and Fraser** collected qualitative data from 20 exemplary teachers and a comparison group of non-exemplary teachers. The purpose of the study was to ascertain how exemplary teachers and non-exemplary teachers differ. Exemplary teachers, unlike teachers in the comparison group, maximized student engagement through the use of appropriate management strategies, stressed cognitively-demanding academic work, and maintained a congenial psychosocial learning environment, report Tobin and Fraser.

Tobin, Treagust, and Fraser compared biology teachers. An interpretive research methodology was used to identify teaching behaviors that distinguished one exemplary biology teacher from five biology teachers identified as non-exemplary. The findings are a mirror image of those of Tobin and Fraser, with the exemplary biology teacher also regularly using inquiry-oriented investigations.

Fraser, Tobin, and Lacy focused on science teaching in elementary grades. Features prominent in exemplary classes that were absent from non-exemplary classes included materials-centered science lessons, effective teacher questioning, and the encouragement of students to formulate and test predictions. Additional data collected with the My Class Inventory revealed that students in the exemplary classrooms perceived their classroom environment more favorably than did students in non-exemplary classes.

Fraser and Tobin compared the student classroom psychosocial environment of 20 exemplary teachers with their non-exemplary counterparts. Student data were collected with the Classroom Environment Scale or the My Classroom Inventory. Students viewed classroom environments created by the exemplary teachers as much more favorable than those of non-exemplary teachers. Student perceptions of the classroom environment, the authors reported, can be used to distinguish classes of exemplary from non-exemplary teachers.

In a case study in Western Australia, **Tobin and Garnett** compared the teaching practices of two elementary and two secondary teachers to identify the ingredients of outstanding science teaching. The teachers were nominated as outstanding teachers by key Australian educators. Interpretations of the classroom observations indicated that inadequate content knowledge is a major barrier to effective science teaching, particularly at the elementary level. All four teachers possessed sufficient pedagogical knowledge to succeed with classroom management concerns. An inability to provide appropriate feedback to students, and to effectively discuss the content addressed in lessons, were attributed to inadequate knowledge of science content. Training science specialists for the elementary schools and researching how teachers amass pertinent content were identified as ways to improve science teaching.

Tobin, Espinet, Byrd, and Adams also explored the factors that shape the instructional practices of a recognized, exemplary science teacher. The setting for the study, however, was a rural high school in the southeastern United States. Observers collected data over a four week period, and students and their teacher were interviewed. The data led the authors to five assertions regarding this teacher's instructional practices: completing work on schedule was emphasized over student learning; the assessment schedule influenced the nature of the academic work; strategies adopted by both teacher and students reduced the cognitive demands in science classes; a small number of target students dominated whole-class interactions and laboratory activities; and, differential teacher expectations for classes and students influenced the nature of the academic work. Teachers' conceptions of teaching and learning fail to provide students with the experiences that consider their current knowledge and the ways they make sense of science information.

Focusing exclusively on student learning outcomes, **Yager** (a) compared the attitudes of students involved in an exemplary science program with those held by students in general. The attitude objects were school science and science teaching. The sample consisted of secondary students who responded to the National Assessment of Educational Progress battery in 1982 and 1984 and ninth grade students enrolled in an exemplary physical science program who responded to items drawn from the battery in 1986. The results of the study indicated group differences, with students in the exemplary program reporting more favorable perceptions of their science course and science teacher. They also viewed science as more useful. Acknowledged by the author is the fact that the National Assessment of Educational Progress does not report data for ninth graders, thus the results of the study must be interpreted with caution.

Yager (b) also assessed the impact of a National Science Foundation funded project where new teachers and their students worked with exemplary science materials and with teachers judged to be exemplary. The exemplary teachers assisted new teachers through inservice workshops, prepared curricula, presented papers at professional meetings, and wrote articles for teacher journals. The project successfully equipped exemplary teachers with the materials and skills necessary to help new teachers improve their instructional practices.

3.42 What characteristics are common among exemplary teachers?

Finding that effective teachers are common to exemplary science programs, **Yager** (c) (also see **Yager, Hidayat, and Penick**) identified characteristics that differentiate most effective from least effective teachers. Assisted by 61 science supervisors, data were collected from the personnel records of 321 teachers. Science teacher effectiveness was assessed with criteria generated from the work of Weiss and Bonnstetter. Examples of criteria included on the list are the following: teachers were eager to share ideas concerning their curriculum and teaching strategies; they established science clubs and other forms of student involvement beyond the classroom; and, they responded as leaders by implementing new ideas. Teachers identified as most effective by their science supervisors participated in significantly more NSF institutes and elective inservice programs than did their colleagues considered to be less effective. Significantly more females were selected as least effective. According to the author, this finding may be related to the identification of science as a masculine field, or the fact that the majority of science supervisors were male. The findings suggest, according to Yager, that one's desire to improve is perhaps the only true difference between the best and worst science teachers.

Guyton compared the personality and demographic characteristics of outstanding, regular certified, and provisionally certified secondary science teachers (n = 74) in Mississippi. The outstanding teacher group consisted of teachers nominated for the Presidential Award for Excellence in Science Teaching. Personality traits were measured using Cattell's 19 Personality Factor questionnaire. The findings revealed that outstanding teachers think more abstractly, prefer to make their own decisions, and are more resourceful, venturesome, socially assertive, and self-assured than other teachers. The outstanding teachers were also found to be significantly older and more experienced than the provisionally certified teachers.

3.5 Invited Commentary — Frances Lawrenz

The research summaries presented in this section offer a diverse view of science programs. The organization into subsections of status, perceptions, evaluation, and exemplary is helpful and facilitates consideration of the twenty-seven studies. This organization scheme is also a developmental sequence beginning with descriptions of existing programs both actually and as perceived, moving toward evaluation of existing programs, and concluding with analysis of programs and components identified as exemplary. The studies are almost all unique and focused on independent populations so generalizations are difficult. Although diversity can be a strength, in this situation it seems that the diverse nature of these studies exemplifies a major problem in science program research: The lack of comprehensiveness. The weakness is a lack of coordination among the different stages of research exemplified by this chapter's organizational categories. Each individual piece of research is limited and tends to raise more questions than it answers. It is not common for status surveyors to have the opportunity to follow up with program development and evaluation that is tied to the survey results. Further, it is even less common to study programs after implementation to identify continuing strengths and weaknesses. More synthesis of the various types of program research presented here is needed.

Status studies have several limitations. Surveys are usually severely limited in scope through funding or client constraints. The excellent status surveys conducted by Iris Weiss for the National Science Foundation provide important data and are quite comprehensive, but even these fail to address some important issues because of space considerations. Also, those data are designed to provide a national picture and may not adequately paint the local picture. Although locally conducted surveys can provide more accurate pictures, they are constrained by funding and access to survey methodology expertise. In addition to constraints on the number and type of questions and respondents, survey sampling techniques and response rates can be critical. Another difficulty with surveys (as with all data collection instruments) is validity. Do the questions really ask what we want to know? Are the respondents answering the questions we intended to ask? Were the people selected to respond the best ones? Can the respondents accurately answer the questions? Are the answers we perceive the ones the respondents intended, etc.? It is important to carefully pilot test all instruments and, if possible, corroborate any traditionally obtained survey information with observation or interview data.

The seven status studies described provide interesting information about some unique science programs and science program audiences. The data provided by these will be useful to others contemplating program development or in comparing their local situation with others. The two studies on specific content areas demonstrated the possibility of transfer of local status information to other similar areas, e.g., Iowa and Kansas, which extends the usefulness of local surveys. The findings for energy education in Australia mirror findings in programs across the U.S., also supporting the possibility of transfer. In addition, according to the reported summaries, at least three of the studies supplemented their surveys with interviews and observational data. Inclusion of these additional types of data improves validity, enhances the interpretation of the survey data, and enriches the data base.

The summaries of the five perception studies show that these were predominantly survey research like the status studies so the same limitations discussed previously apply for these studies as well. Perception studies are even more subject to validity weaknesses and often incorporate self report bias. Respondents can sometimes report what they think they should feel rather than what they actually feel, and many people are reluctant to be very negative. Assessing change as described in these studies can be useful in two ways. First, it is important to view status (perceptual and actual) in a longitudinal sense—one of the values of status studies is that they can provide the opportunity to look at change over time or across locations. The second advantage is that change scores can be less biased or rather the bias should be the same in both instances and the absolute score is no longer the score of interest. Problems that arise in change scores are more likely to be in tracking or selection of groups. The idea of "sameness" for the two or more groups must be carefully considered.

The area of community or administrator perception that is covered in two of the studies reviewed here is one that has not been researched much in the past and may be one of the important areas for future study. As competition for funding becomes more keen, a political awareness at both the local and national levels will be vital. In addition, research has shown that schools are most effective when they are supported by and support the beliefs of their constituencies. Awareness of these belief patterns would be an excellent beginning for program development. The summary of the study by Harty, Kloosterman, and Matkin also mentions the use of a good technique to employ in this type of research. They used a follow-up telephone survey to help validate findings from their mail out survey.

Three of the four evaluation studies summarized here focused on SCIIS and provide a variety of data about this program. The complementarity of these three studies demonstrates the effectiveness of the SCIIS program and of combining different, smaller studies using different techniques with different populations in providing a more adequate evaluation. Effective program evaluation is usually very comprehensive and consequently quite expensive. The combination of several less comprehensive studies may help to answer the question of how to provide inexpensive but comprehensive evaluation. Certainly this has been effective in the past with meta-analyses and other summarizing techniques, but coordination of the independent studies beforehand would greatly facilitate their use for evaluation purposes. One of these studies also demonstrates the richness of results offered through the inclusion of observational as well as student and teacher data.

The fourth evaluation study provides an example of the type of program research that should perhaps be conducted more often: The comparison of a program, or in this case its assessment, with its philosophy. This type of evaluation along with that described by Stufflebeam as contextual or analysis of goals is not conducted nearly enough. We often assume that stated goals are what we want without seriously considering them. The next steps of carefully delineating how well planned programs fit with these goals and how well programs as implemented match what was planned are also not followed as often or as rigorously as possible. The emphasis in the past has been more on what happened not on why this should have happened.

The remaining 11 studies focus on exemplary teachers. Five of these were conducted as part of the Australian Exemplary Practices Program and provide comprehensive data utilizing a variety of data collection formats and sources to clarify characteristics of exemplary teachers. Studies comparing the characteristics of teachers and their students identified as exemplary in the U.S. were also conducted. The findings were generally what you would expect with the exemplary teachers being more motivated and motivating, having better science content knowledge, providing more favorable environments, and producing students who are more knowledgeable of and more positively inclined toward science.

The results of one case study as reported here (Tobin, Espinet, Byrd and Adams), however, were counter-intuitive and raise the specter of inconsistent or inaccurate criteria for the identification of what is exemplary, the "chicken or egg" nature of the identification of what is exemplary, and the delineation of characteristics. In this study the exemplary teacher was seen as putting greater emphasis on completing work on time than on student learning, allowing the assessment schedule to influence the nature of academic work, employing strategies that reduced the cognitive demands of academic work, having small numbers of target students, and using differential teacher expectations for classes and students. On the surface none of these practices appears to be exemplary. Obviously more in depth study needs to be done.

4.0 Curriculum

Reviewed in this chapter are studies from the areas of science learning in nonformal settings (3 studies), Science-Technology-Society (6 studies), textbooks (10 studies), and curriculum development (6 studies). Studies within the first area deal with museum visitors, zoomobile programs, and characteristics of formal, nonformal, and informal science teaching. Included in the Science-Technology-Society section are studies concerning teacher perceptions, religious orientation and attitude toward Science-Technology-Society issues, as well as student learning outcomes. Within the textbook section studies examine textbook difficulty, level of textbook abstraction, stereotyping, treatment of theory, and the presentation of unifying concepts. Studies in the final section focus on systematic development efforts, relationships between the intended and achieved curriculum, pre-planning evaluation, assessment techniques, and student involvement in curriculum development.

4.1 Learning in Nonformal Settings

4.11 What factors influence attentional behaviors in museums?

Dierking studied parent-child attention-directing behaviors in a museum to determine if frequency of attentional behaviors are affected by exhibit type, age of children in a family, and gender of parent-child dyads. Data collected from 56 families revealed that questioning is a dominant behavior in the family museum experience. Questioning was found to be influenced by interactivity of the exhibit, age of the children in the family, and dyad type.

4.12 What variables are common among zoomobile programs?

Wood and Churchman surveyed the literature on zoomobile programs. They found that most programs rely on vans for transportation and on volunteers for staffing. Schools, hospitals, and nursing homes are the major beneficiaries of zoomobile programs. The animals are small and often non-releasable rehabilitants. Programs are tailored to the audience in terms of depth of material and length. Some programs charge a fee to cover expenses, but those affiliated with public zoos are free. Wood and Churchman recommend dovetailing wildlife education with the regular classroom curriculum.

4.13 How do formal, nonformal, and informal learning experiences compare?

Maarschalk identified two stages of research that foster scientific literacy: composite saturation and smaller, more manageable portions. Within this context formal, nonformal, and informal science teaching were also compared. In contrast to formal and nonformal science teaching, informal science teaching comes about within life situations, e.g., a spontaneous discussion among friends (informal) after viewing Cosmos (nonformal) that might influence activities in a science class (formal). The author describes briefly the ongoing work of comparing formal, nonformal, and informal science as part of the Rand Afrikaans University Scientific Literacy Research Project. One of the project's foci is the development of instruments to assess informal science teaching.

4.2 Science-Technology-Society

4.21 Are the processes emphasized by Science-Technology-Society part of the standard high school curriculum?

Legorreta surveyed 242 high school science teachers in three southwestern states to determine their perceptions of the emphasis placed on STS processes in current science curricula. Questions probed the emphasis placed on problem-solving and decision-making skills, applications of science, ethical considerations, values clarification, and career awareness. Teachers' responses revealed that the textbook-based, high school science curricula used in the tristate area do an adequate job of the following: illustrating the applications of science outside of the classroom; preparing students for life in a scientific-technological society; and, stimulating student interest in further study of science in school. Experiences that stress decision-making skills and exploration of science-related ethical problems were lacking in the current curricula, the teachers reported.

4.22 How are religious orientation and attitudes toward Science-Technology-Society issues related?

Science chairpersons (n = 556) from northeastern secondary schools were surveyed by **Lombardi** to assess the relationship between religious orientation and attitude toward STS issues. It was hypothesized that Catholic school chairpersons would have a more religious orientation than chairpersons at public schools. Attitude toward STS issues was not related to religious orientation. However, the assertion that Catholic school chairpersons possess a more religious orientation than do chairpersons at public schools was supported.

4.23 How do experiences with a Science-Technology-Society focus compare with traditional experiences?

Mesaros compared the effect of traditional instruction and STS instruction on achievement, long-term retention, and interest of ninth and tenth graders. The experimental manipulation was the inclusion of nuclear energy investigations and discussions into the biology and introductory physical science curricula. Matching classes served as controls. No difference was found between the two instructional approaches in terms of achievement and long-term retention. However, according to the researcher's observations, students in the experimental classes displayed more interest toward the STS investigations and discussions.

Zoller, Ebenezer, Morley, Paras, Sandberg, West, Wolthers, and Tan probed the effect of Science and Technology 11 (ST 11), an elective course designed for eleventh graders in British Columbia , on students' STS related beliefs. The experimental group consisted of 101 randomly selected students who had completed the ST 11 course during the previous year. The control group included 276 randomly selected students who had not taken ST 11. The measure was four statements selected from the Views on Science-Technology-Society instrument developed by Aikenhead. According to the authors, the ST 11 course did have the desired impact on the experimental students.

To better understand the success of STS programs, **Yager, Blunck, Binadja, McComas, and Penick** tested students in 300 Iowa classrooms, grades four through nine. One group experienced traditional science and another experienced science with an STS focus. The classes were compared on five domains of science education: connections and applications, attitudes, creativity, process skills, and science content. Students exposed to an STS experience were superior to students in traditional science courses on the following outcomes: ability to apply information to other situations; attitude toward science, science instruction, and science teachers; creative behavior; and, ability to perform basic science process skills. Students in the STS course also acquire an equivalent amount of science content knowledge.

4.24 What is the preferred testing format for assessing students' beliefs about Science-Technology-Society topics?

Aikenhead compared the degree of ambiguity associated with four kinds of assessments used to monitor beliefs about STS topics. Twenty-seven, twelfth grade students representing two Canadian high schools and a wide range of student achievement responded to statements from the Views on Science-Technology-Society (VOST) in four ways: Likert-type "agree", "disagree" or "can't tell"; a written paragraph justifying personal reactions to VOST statements; a semi-structured interview; and, the choice of STS positions empirically-derived from student paragraphs. From the most to least ambiguous, the four response modes were sequenced as follows: Likert-type statements, written narrative, multiple choice, and interview. Although the interview generated the most unambiguous data, its liability of time prompted the author to recommend the use of the empirically-derived multiple-choice response mode which was found to be unambiguous about 80 percent of the time. The Likert-type data provided little more than a guess about STS beliefs. However, the author was quick to explain that Likert statements are valid only for measuring attitude; VOST statements stress cognition. Aikenhead also sought to determine the source of the STS beliefs. Seventy-three percent of the students cited the media as the source of their beliefs. Ten percent cited science class, and no one mentioned science textbooks.

4.3 Textbooks

4.31 Is the reading level of textbooks too difficult?

Wood and Wood assessed the reading comprehension levels of 10 fourth grade science textbooks published between 1979 and 1981. The results revealed the following: the reading indices provided by publishers do not adequately convey the reading levels that are implemented throughout the textbooks; only 5 of the 10 textbooks examined can be read at 50 percent comprehension level by fourth graders reading at grade level; for fourth graders reading in the lower quartile and for fourth graders of low socio-economic status (SES), 7 of the 10 textbooks are too difficult; and, for high SES fourth graders reading at grade level, 9 of the 10 textbooks can be read without difficulty. According to the authors, attempts by publishers to make elementary science textbooks more readable have been unsuccessful.

Sellars examined the readability of select high school science, social studies, and literature textbooks to determine whether the textbooks are appropriate for students who read them. Difficulty was determined by an exact-word cloze test that was administered to 772 students. The results indicated the following: only eight percent of the students were successful when attempting to read the texts; science and literature textbooks were more difficult than social studies texts for both tenth and twelfth graders; and, literature textbooks were less difficult than science and social studies books for eleventh graders. The researcher recommended that secondary school teachers teach reading skills in the content area. They should also consider alternatives to textbook reading assignments.

4.32 How do elementary textbooks compare?

Meyer, Crummey, and Greer systematically analyzed elementary science textbooks published by Holt, McGraw-Hill, Merrill, and Silver-Burdett. Compared and analyzed were the textbooks' content domain, presentation of content, a count of propositions, and finally, considerateness, i.e., logical structure of narration, proximity of referents and antecedents, background knowledge in text, pertinent illustrations, etc. Textbook inconsiderateness did not prevail. Series with the most text (i.e., content domains, thought units, and vocabulary) also included the most hands-on activities, and they embraced less text inconsiderateness. The authors concluded that elementary science textbooks cannot be dichotomized as either content-based or hands-on.

4.33 Is stereotyping common in elementary textbooks?

Powell and Garcia examined and evaluated about 6,000 photographs and illustrations appearing in 42 elementary science textbooks. Their efforts revealed the following: men appear twice as often as women; men are depicted more often as science professionals than are women; adult members of minority groups are shown in traditional science related roles in less than one-fifth of all photographs and illustrations; girls are pictured actively engaged in science activities slightly more often than are boys; and, minority children are pictured less frequently than Caucasian children. The authors encourage teachers to discern the subtle social messages presented in science textbooks.

4.34 How is theory treated in middle school life science textbooks?

Lerner and Bennetta define theory in two ways. Their first definition depicts theory as something that makes possible the comprehension and prediction of a certain class of phenomena. Their second definition presents theory as a unifying theme that is at the heart of an entire science. Relying primarily on the second definition as the basis for argument, the authors analyzed three junior high school life science textbooks (Prentice-Hall Life Science, Merrill's Focus on Life Science and Scott, Foresman Life Science). Their analyses revealed the following: scientific theories are often equated with myths, beliefs, and legends; creationism seems to contribute to the misuse of the term "theory;" and, historical accounts of the development of theories are often misleading.

4.35 How are unifying concepts presented in textbooks?

Prompted by the position that the rock cycle is a unifying concept in physical geology, **Eves and Davis** probed nine introductory physical geology textbooks for rock cycle diagrams and discussions. Two of the nation's leading sellers (The Earth's Dynamic System, fourth edition by Hamlin and Earth, fourth edition by Press and Siever) failed to mention the rock cycle. The other seven texts did, in varying degrees, diagram and discuss the rock cycle.

Ellse inspected science textbooks used by 11 to 13 year olds in the United Kingdom to assess the presentation of energy concepts. He concluded that drawing student attention to energy transformation and asking students to identify the energy changes that take place in a system fosters confusion. Rather than stressing energy transformation, the author urges that the process of energy transfer be stressed within energy concepts. For example, teaching students how energy is transferred when two wooden blocks are rubbed together makes energy concepts more understandable to all students, particularly those who are not formal thinkers.

4.36 How are methods of evaluating reading materials related?

Vachon (also see **Vachon and Haney**) developed a procedure for scoring the level of abstraction (LOA) of science reading materials and compared its to other known methods of evaluating science reading materials. Nine passages from life, earth, and physical science textbooks written for three different grade levels were tested. The subjects were 425 urban students in grades 5, 7, and 10. Statistical analyses revealed non-significant correlations between students' cloze scores and passage readability level and level of abstraction. Significant correlations were found between students' cloze scores and teachers' predictions of student comprehension level and standardized reading scores. According to Vachon, the high, but non-significant correlations between the LOA and cloze scores, coupled with the fact that the LOA is based on deep structure of written material, warrants further study of the LOA.

4.37 How do students approach a new reading assignment?

Responding to **Wandersee's** six-item questionnaire, Preferred Method of Study, 133 undergraduate education students explained how they approach textbook reading. Student interviews served as a pilot study for the development of the instrument which was designed to simulate what happens in a clinical interview process. Records provided information on college rank, grades, and gender. From their written responses to questions on the instrument, Wandersee measured the number of passes made by each student, where a pass was defined as one try at reading, outlining, taking notes, etc. The number of student passes was significantly correlated with grade point average. Females were more likely to use a single study strategy than were males. Less than half of the subjects accompanied reading with self-fashioned tools, such as diagrams or outlines. The type of test expected by students altered study strategies more than the type of subject matter. Only six percent of the subjects made a conscious effort to link new concepts to prior learning. College rank was found to be unrelated to student study strategies. Too detailed to review here are the author's analyses of select student responses made to the eight questions on the instrument.

4.38 Does decision-making augment recall of text material?

At the request of **Pedersen, Bonnstetter, Corkill, and Glover** 59 high school students, randomly assigned to four groups, read the same 2600-word essay covering 255 propositions on nuclear chemistry. Immediately following a 40-minute reading period, each group was confronted with one of the following treatments: seven questions requiring a yes/no decision, the same information in seven declarative statements, and the same information in seven rephrased questions but not requiring a decision. A control group read slowly and prepared for a test. Following treatment, students were directed to write down everything they could recall from the essay. Two independent raters tallied the number of essay propositions embodied within the written responses which served as the posttest for each subject. Subjects who made decisions recalled significantly more propositions than did students in the other three groups. Students who responded to questions but made no decisions recalled more proportions than did subjects who read the statements and subjects who were in the control group. In a second experiment where posttesting was delayed one week, the results confirmed those of the first experiment and extended the outcome to include long-term recall. According to the authors, the results of the two studies suggest that decision-making augments both short- and long-term recall.

4.4 Curriculum Development

4.41 What are the results of curriculum development efforts?

The results of a survey conducted by **C. L. Brown** led to the development of a model course in advanced biology for North Carolina schools. The model course highlighted six areas: teachers, logistics, subject content, other content (e.g., science process skills and the nature of science), instruction, and facilities/materials. To determine the acceptance of the model course, advanced biology teachers and science supervisors, university biologists and science educators, and state science supervisors were surveyed using a questionnaire that encompassed 49 statements representing the six areas of the model course. The survey resulted in the rejection of only one of the 49 propositions. Also, a high school course in physics was recommended to precede advanced biology.

Dori, Hofstein, and Samuel analyzed the development, implementation, and evaluation of a chemistry course for use in nursing schools in Israel. The curriculum was designed to meet the needs of entering students who had studied chemistry for one year or less. The goals of the course were the following: provide the basic chemical understanding required for advanced nursing courses; make the content understandable for students with diverse backgrounds in science; and, increase the students' interest in chemistry. The new course, completed by 400 nursing students, was implemented in 10 nursing schools in 1985. According to the authors, the new curriculum served as an introductory chemistry course for nursing students of diverse chemistry backgrounds, enhanced the students' image of chemistry, and reduced the anxiety often associated with the study of chemistry among nursing students.

4.42 How related are the intended, translated, and achieved physics curriculum?

Finegold and Raphael scrutinized the relationships of the physics curriculum in Canadian secondary schools at three levels: the intended curriculum, represented by an explicit set of aims; the translated curriculum, consisting of the teaching-learning milieu of the science classroom; and, the achieved curriculum, that which individual students internalize. At the intended level curriculum documents were evaluated. At the second level, data gathered on teacher perception and actual classroom practice were compared. The achieved curriculum was revealed through examination of science achievement test and attitude questionnaire results. The findings revealed limited but significant relationships among the three levels.

4.43 What is the effect of pre-planning evaluation on curriculum development?

Tamir (a) investigated the role of pre-planning evaluation (PPE) in developing an electricity curriculum for use in technical high schools in

Israel. PPE is a data source used by curricular developers to make pre-planning decisions and to identify problems. According to the author, PPE prevents curricular developers from overlooking issues that may impact the curricular development effort. Four commonplaces, namely the teacher, the student, the subject matter, and the milieu, were the foci of the PPE model. A pre-planning report highlighting the four commonplaces utilized data gathered from a number of sources including students and teachers of electricity, electrical engineers, graduates specializing in electricity, and employers of graduates of the technical schools. For purposes of the study, the Israeli Ministry of Education appointed five independent committees to design a new electricity curriculum. Each committee was provided with slightly different pre-planning evaluation information. Groups that were provided no information or incomplete information spent more time engaged in deliberations, failed to recognize curricular problems nor suggest needed improvements, and focused primarily on subject matter concerns. In comparison, the group that received all available pre-planning evaluation information spent more time translating subject matter objectives into learning experiences, and they emphasized the syllabus and its implementation during deliberation.

4.44 What effort is being invested to develop teachers' assessment skills?

Leith explored the effects of providing limited support to teachers on their development and use of science assessment techniques in the classroom. Sixteen teachers from eight elementary schools in the Fife region of Manitoba, Canada, were provided with a variety of instructional materials and met biweekly at their schools to discuss and plan assessment strategies with the author. The results of the initiative, which ran from February through July, 1987, disclosed that elementary teachers can develop their own personal means of assessment and record keeping in science. The participants assembled a package of instructional materials for consultants and course leaders to teach others how to enhance science assessment skills.

4.45 How promising is student involvement in curriculum reform?

Liske sought to explore the effect of involving students in the revision of a technology curriculum. Two poorly motivated, highly anxious students, representative of the population for which the materials were intended, received pay for working with one of the original authors of the curriculum. The students were helpful in identifying problems related to textual clarity, sequencing of material, and the placement of charts and pictures. The greatest contribution made by the students, according to the author, was the provision of feedback about activities and experiments. Liske concluded that collaborative curriculum development efforts with students can result in the production of high quality instructional materials.

4.5 Invited Commentary — Glen Aikenhead

A science curriculum is the end result of a series of "negotiations" among the teacher, the student, the subject matter, and the milieu (Schwab's commonplaces). The ultimate goal of any science curriculum is to ensure that students learn and develop in specified ways. The teacher, the subject matter, and the milieu all affect what a student learns. Central to the curriculum, therefore, is the student. From this student-centered perspective on curriculum, I offer the following reaction.

Research associated with the science curriculum can be discussed in terms of how closely the results relate to student outcomes; that is, the extent to which we must make inferences about the associations between the research results and student learning and development. It is interesting to read the 1988 review of science curriculum research from such a perspective.

Study 4.42 suggests that our inferences about the curriculum's impact on student learning are made on very "thin ice" (i.e., very small correlations). The intended curriculum (government documents) have little effect on teachers' ideas of what students should learn (the translated curriculum); and, both the intended and translated curricula are only slightly related to what students actually learn. Studies 4.11, 4.23, 4.24, 4.38 and 4.45 (among others) focus on students — the ultimate goal object of the curriculum. These studies require the least amount of inference on the part of the reader. By paying attention systematically to students, researchers discovered (a) a complexity of interactions in museums that defy simple prescriptions for practice (4.11); (b) that STS content increased students' interest without compromising their achievement, and that STS content was able to affect student learning and development in specified ways (4.23); (c) that when developing evaluation instruments or classroom materials, full collaboration with students yields dramatically positive results (4.24 & 4.45); and, (d) that decision-making questions requiring active critical thought caused students to learn more content than did normal questioning and summarizing strategies (4.38).

Studies related to the teacher are often based on the assumption that the teacher makes a difference to student learning in predictable ways. While it is common knowledge that the teacher makes a difference, one cannot be so confident about the predictability of those differences. We read (4.44) that teachers' skills at assessing students can be increased, but we must assume that this will improve what students learn. We read (4.21) that teachers in a particular region believe their curriculum does an adequate job at meeting some STS objectives, cited as "adequate", which actually became the achieved objectives, and that by placing the missing objectives into the curriculum they too will somehow affect student learning in predictable ways. We read (4.22) that religious orientation is not related to attitudes toward STS issues, but we must assume that STS curriculum outcomes for students are not differentially affected by a religious or secular teacher.

The subject matter commonplace of the curriculum may be represented by the products of science curriculum development, including textbooks. A study (4.41) shows that "model" courses (i.e., those receiving consensual approval by a panel of experts) can be designed theoretically, but we must assume that model courses lead to model learning and development on the part of students. On the other hand, however, client-targeted courses (e.g., chemistry for nurses) can successfully meet the needs of students when such needs have been empirically discovered and empirically evaluated with students. Studies which found that textbooks are too difficult for students to read (4.31) assume that textbooks publishers treat students as the client. This assumption cries to be investigated! One study cites evidence to the contrary. For teacher committees deciding which texts to adopt, evaluation information makes their decisions more rational (4.32), but the connection to student learning is still tenuous. Studies which look at stereotyping in textbooks presume detrimental effects on children (4.33). Surely these presumed effects are worth investigating. Instead, 42 elementary science texts were analyzed in order to document the adult perception of stereotyping. The presentation of subject matter in textbooks (e.g., nature of theory, the rock cycle unifying concept, and energy concepts) is assumed to make a difference in what students learn (4.34 & 4.35). Do students pay as close attention to epistemological and scientific concepts as researchers do? This is an empirical question, begging systematic study. (Study 4.24 found that students do not pay attention to the misconception of "the scientific method" found in many texts. Why would students pay any more attention to textbooks' misconceptions about scientific theory?) Study 4.37, on the other hand, found that student interaction with text materials is largely an idiosyncratic process. The study wrestled with a wealth of detail required to analyze students' reading strategies. The researchers in study 4.37 worked closely with students, and as a consequence, the reader is not left to make far reaching inferences about student outcomes.

All four commonplaces of the science curriculum were researched in 1988. Reading these accounts, I perceived the following pattern: the closer the research touched the student, the more confident our prescriptive inferences became; but, the closer the research touched the student, the more difficult, complex and messy the research became. It is much easier to have teachers respond to questionnaires than to investigate the effect of the teachers' instruction on student learning and development. Teacher questionnaires do have their place, but only when one is interested solely in the teacher (e.g., the evaluation of an inservice project). When implicit implications are made about improving the quality of instruction, then it seems to me that questionnaires ought to be abandoned, or at least involve students. Happily, on the other hand, 1988 saw carefully crafted studies embrace a complexity of issues related to the science curriculum.

5.0 Instruction

The studies examined in this chapter are divided into three areas, teaching methods and strategies, the learning environment, and the learning cycle. By far, the majority of the studies (15, in all) deal with teaching methods and strategies. Studies focus on alternative instructional methods, mastery learning, instructional strategies used in African nations, the utilization of inquiry methods, and teachers' science process orientation and instructional patterns. Only three studies reported in 1988 examined the science learning environment (2) or the learning cycle (1).

5.1 Teaching Methods and Strategies

5.11 What are the effects of alternative forms of instruction on student learning?

Relying on historical and quasi-experimental research methodology, **Miller** assessed outdoor education as a supplement to the traditional science curriculum. Historical research revealed the following information: John Locke provided the impetus for encouraging the use of outdoor education; Jean-Jacques Rousseau advanced Locke's pedagogy; and, John Dewey exemplifies American educational theorists who endorse outdoor education. Comparing the outdoor education model to traditional instruction, results suggest that students retain information better if learned through outdoor education.

A descriptive study conducted by **Reynolds** assessed the effect of writing plus reading and other class activities on achievement in biology. Data consisted of daily recordings in journals, audiotaped interviews, reading and writing assignments, and responses to an attitude survey. Writing helped the students perform better in such cognitive activities as grasping ideas, seeing other points of view, and learning broad ecological objectives. Moreover, writing and reading elicited student thinking identified as reflective, interpretive, and projective, and resulted in some improvement in attitude toward writing in science. Reynolds concluded that different modes of writing combined with reading and other class activities effectively aid learning.

Baker compared student-directed to teacher-directed modes of instruction to assess change in chemistry students' understanding of density. Subjects were drawn from nine classes in two high schools. Two instructional units incorporating the same content highlighted both modes of instruction. Treatment effects were assessed by open-ended questionnaires administered immediately prior to and following instruction, by structured interviews completed a week later, and by problem sets completed several months after treatment. Mode of instruction had little effect on student understanding of density.

In a two phase study, **Maroufi** compared the effects of generative (i.e., discovery, undergirded by schema theory) and traditional methods of science instruction on retention of facts and concepts and their applications. Student attitudes were assessed, too. The first phase involved two intact groups of eighth grade students receiving generative or traditional lessons on the topics of planets and gases. No significant cognitive differences could be attributed to either method of instruction. However, students receiving traditional instruction held significantly more favorable attitudes toward their method of instruction than the experimental group held toward the generative method. The second phase tested generative instruction in two socioeconomically-different schools. Written and oral student responses gleaned from video tapes served as the data source. According to Maroufi, students in higher socioeconomic schools fostered the cognitive dispositions (e.g., higher aptitude, self- directed, competitive) needed to do well in a generative learning environment.

Continuing the search to identify an optimal way to teach scientific literacy, **Callison** compared the efficacy of two approaches to teaching general science courses to non-science majors. Both approaches emphasized science content, but the traditional approach included laboratory observation, whereas the four-fold approach stressed learning skills. Specifically, subjects in the four-fold group were taught how to capture the essence of a lecture, judge the value of the lecture in terms of its content and form, select a part of the lecture and expand upon, and plan a lesson around a select part to be taught to someone else. Data were collected one year after the treatment from students who had experienced the two approaches. Both approaches rendered high knowledge retention and an acceptable level of scientific literacy.

Calkins tested the effectiveness of a marine education video program with students of different ages, grade levels, and levels of cognitive development. Results revealed that video is an effective way to transmit information about marine-related issues and that the efficacy of the program is moderated by the viewer's level of cognitive development.

Using a pretest-posttest, quasi-experimental design, **Brasil** tested the effect of expository and discovery strategies on student learning and application of thermochemistry principles. The results revealed that both strategies enhanced cognitive transfer although the college students subjected to the expository treatment learned more and better applied thermochemistry principles. Moreover, the success of the discovery strategy was influenced by pre-existing student characteristics such as cognitive development, age, and mathematics background. The expository strategy was not affected by these characteristics.

Metz compared the effect of interactive instruction and lectures on chemistry achievement and attitudes. One hundred thirty-seven students enrolled in a lower level, college chemistry course served as subjects. One-half of the students received instruction by lecture, and the other half engaged in a learning experience which included probing questions, confrontations, demonstrations, and problem solving. Four 50-minute examinations and a comprehensive final examination measured achievement, and a 15-item questionnaire measured students' attitudes toward the method of instruction. Students taught by the interactive method performed equally well on the examinations as those who where taught by lecture. Perhaps more importantly according to Metz, the attitudes of students taught by the interactive method were significantly more favorable than those of students taught by lecture.

Carey, Evans, Honda, Jay, and Unger compared the effectiveness of two science units designed for seventh graders. The experimental unit consisted of a series of lessons on the nature of yeast and contained linguistic aids, augmented by computer-assisted instruction. The control unit taught terminology of the experimental method, and it stressed the collection of reliable data. No significant group differences were found on tests of the nature of science, scientific inquiry, and the logic of experimentation. Interview data, however, favored the experimental group. Based on the results of the first experiment, the experimental treatment was modified. For the second experiment, daily observations and teacher comments were also collected. Students in the experimental group developed clear distinctions between ideas and experiments, considered verification or exploration of an idea as motivation for conducting an investigation, and appreciated the relationship between testing an idea and results of an investigation. The authors concluded that the experimental treatment succeeded in developing students' understanding of the nature of science.

5.12 What are the effects of cooperative and individualized mastery learning on achievement and on-task behavior?

Lazarowitz, Hertz, Baird, and Bowlden probed the effects of a cooperative, mastery-learning approach versus an individualized mastery-learning approach on students' on-task behavior and achievement. The cooperative method employed a slightly modified jigsaw. Here students were expected to learn a part of the lesson. Then they left the jigsaw group and formed counterpart groups composed of students from other jigsaw groups who were given the same assignment. Information learned in the counterpart groups was then taught by the attending group member to other members of the jigsaw group. The learning materials were units on the cell and plants. Achievement was assessed with teacher constructed tests, and on-task behavior was monitored by trained observers. Students who participated in the cooperative, mastery-learning group spent more time on-task both during the experimental treatment and later than did students exposed to the individualized approach. The effects of the treatments on student academic achievement were mixed. Students exposed to the cooperative approach scored significantly higher on the cell unit test, but significantly higher scores on the plant unit test were earned by the students who worked by themselves.

5.13 What expository styles of teaching are predominant among teachers in African nations?

Using the Science Teaching Observation Schedule, **Williams and Buseri** investigated 54 biology, chemistry, and integrated science lessons for the purpose of analyzing the expository styles used by Nigerian science teachers. Realizing that some teachers are more accomplished in the expository mode than others, they hypothesized that select elements of expository teaching could be identified and then taught to preservice and inservice teachers. Four clusters of verbal discourse emerged from the analyses of the lessons. Thirteen lessons imparted information; factual questioning and simple problem-solving were central in 21 lessons; in addition to extensive questioning of a factual nature, nine lessons focused on discussions of experimental procedures; and, in 11 lessons moderate levels of teachers' statements related to hypothesizing and problem-solving prevailed. When compared to data collected in Britain, Canada, and Indonesia, the analyses revealed that little pupil-pupil and pupil-teacher interaction occurred, and that unfortunately, only in Nigeria was information presented continuously throughout the lesson.

Muthwii analyzed the expository styles and questioning practices of Kenyan chemistry teachers. The Science Teaching Observation Schedule identified the verbal discourse patterns. The sample consisted of 14 chemistry teachers and their students. Of the 77 chemistry lessons recorded 14 were analyzed. The analysis revealed that teacher questions emphasized factual recall. Other than teachers' statements related to hypotheses and problem-solving, the same discourse patterns identified by Williams and Buseri prevailed here. When the Kenyan discourse patterns were compared to those from science classes in Nigeria, Canada, and the United Kingdom, teacher talk dwarfed other discourse patterns.

5.14 What factors relate to inquiry as utilized by secondary teachers?

K. J. Williams sought out the factors that encourage inquiry instruction among secondary science teachers. A 38-item questionnaire was the source of data, and 77.3% of the 318 teachers queried returned it. The statistical analyses revealed significant positive relationships between the use of inquiry and the number of natural science courses and educational methods courses completed. Significant relationships were not sustained between the use of inquiry and the following variables: years of teaching, the number of courses completed in the teaching area assigned, and instructional barriers (e.g., inadequate facilities).

5.15 How are process-oriented teachers unique in teaching behaviors?

In responses to this question, **Lenk** collected data from 234 elementary teachers on three questionnaires. The first questionnaire measured teacher perception of their use of process skills. A second instrument measured process teaching practices in the classroom. Data on academic preparation, professional experience, grade level taught, attendance at professional meetings, and time devoted to science teaching were gathered on the final questionnaire. Teachers committed to a process approach did not devote more time to teaching science. On the other hand, teachers who devoted more time to science teaching used more process teaching practices, and those who held advanced degrees and regularly attended professional meetings manifested a stronger process-orientation.

5.16 Do physics teachers follow similar instructional patterns when presenting the same topic?

Data gathered over a six month period by **Contreras** documented how physics teachers present content to students. When teaching a unit on dynamics physics teachers fragmented a unit of information into topics that, in some cases, revealed few logical connections. Their teaching of Newton's Second Law showed a series of sequential steps where antecedents did not match referents. The organization of instructional materials varied considerably. Contreras concluded that many secondary students experiencing the same science topic learn differently arranged bodies of knowledge.

5.2 Learning Environment

5.21 What factors foster a harmonious student-centered learning environment?

Employing an ethnographic research methodology **Wilkinson, Treagust, Leggett, and Glasson** set out to identify teaching strategies compatible with a harmonious student-centered learning environment. During two six-week periods observations were made of 26 secondary school students enrolled in the first year physics course leading up to the Western Australian Tertiary Entrance Examination. The teacher was a participant on the research team. Additional data were obtained from student tests, work files, lesson plans, class handouts, student and teacher interviews, and student questionnaires. An analysis of the data by the research team generated eight major assertions: the learning environment fostered by the teacher encouraged student understanding rather than rote memorization; activity sheets related new experiences to prior knowledge; activity sheets and note guides actively engaged students in constructing their own understandings; and, student cues on cognitive demands led to the adoption of different classroom strategies. Factors most frequently associated with a harmonious student-centered environment were the teacher's willingness to improvise teaching materials to facilitate student learning and the trusting nature of the teacher in allowing students to accept responsibility for their own learning.

5.22 What is the relationship between students' perceptions of the learning environment and learning outcomes?

Lawrenz tested the relationship of students' perceptions of their classroom psychosocial environment to their energy knowledge and energy attitudes. Approximately 1000 students from 13 fourth grade and 21 seventh grade classes randomly-selected from public schools in Arizona served as subjects. They completed three instruments: the Energy Survey, the Energy Opinionnaire, and the My Class Inventory. Data revealed that student perception of the psychosocial classroom environment predicted from 17% to 59% of the variance in student attitude and energy knowledge scores, with competitiveness and cohesiveness serving as the best predictors for seventh graders and fourth graders, respectively.

5.3 Learning Cycle

5.31 Are all phases of the learning cycle necessary?

Renner, Abraham, and Birnie explored the consequences of omitting one or more phases of the learning cycle. Sixty-two senior high school students enrolled in three sections of a physics course taught by the same teacher served as subjects. One group served as the control and experienced all phases of the learning cycle, while the other two were taught the same physics concepts with phases of the learning cycle omitted. Conceptual Achievement Tests were administered before and after each phase of the learning cycle. Students were interviewed at regular intervals. Results of two experiments led the researchers to draw the following conclusions: allowing students to explore when given nothing more than materials and directions is an inefficient way of learning physics concepts; providing students with a comprehensive explanation of a concept prior to allowing them to interact with materials resulted in minimal conceptual understanding; discussions that lead to conceptual inventions need to follow explorations which yield data; all phases of the learning cycle are considered important to the students; and, under specific conditions one or more phases can be omitted.

5.4 Invited Commentary — Ken Tobin

Science educators concern themselves with the extent to which teachers use the findings of educational research to enhance the science learning of their students. The concerns are sincere, and professional associations spend a great deal of time investigating the reasons for failure to adapt and adopt research findings. With this concern in mind I read the section on Teaching Methods and Strategies. What is here that could be used by teachers to improve science learning? Not much. In my view the studies reviewed in this section are unlikely to persuade teachers to change what they are doing in their science classes. Most of the studies fail to ask fundamental questions that need to be answered, and they make assumptions that do not hold up in most classes.

Two fundamental questions that must be answered by researchers of learning and teaching are: What do teachers do in their science classes? and, Why do they do what they do? If we expect teachers to change we should know what they currently are doing and why they are doing it. Research that I have conducted with my colleagues over an extended period of time (e.g., Tobin & Espinet, 1989; Tobin, Kahle, & Fraser, in press) suggests that teachers have good reasons for doing what they do and are unlikely to make changes unless those changes make sense in the contexts under which they operate. Teachers have to believe that a suggested course of action is appropriate before they will make changes. And if we consider asking teachers to change their beliefs, it seems reasonable to know something about their existing beliefs.

Beliefs of teachers do not always influence classroom practices. For example, teachers might believe that using a wait-time of three to five seconds is conducive to student learning of science but rarely utilize an extended wait-time when they teach. Furthermore, teachers might hold beliefs that imply contradictory actions. Many teachers believe that a wait-time of three to five seconds will increase achievement but that the optimal pacing or momentum of a lesson necessitates a wait-time of less than one second. What course of action should follow if wait-time should be both long and short? This example serves to highlight the complexity of teaching. Most teachers are not torn by questions such as these, instead they do what makes sense in the circumstances. Teachers do what they believe to be right in the given contexts that apply to them as they teach. The evidence from our research program suggests that changes in what teachers believe and what they do in science lessons occur frequently when teachers are convinced of the need for change and the suggested courses of action make sense to them.

How does the current set of studies reviewed in the teaching methods and strategies section take account of what we know about teacher change? Consider the study undertaken by Lazarowitz and his colleagues (Lazarowitz, Hertz, Baird, & Bowlden). What did the teachers in each group believe about cooperative learning? Did they believe that cooperative learning was appropriate in all contexts? How was cooperative learning implemented in the participant classes? It is well to remember that the students involved in a study have beliefs about what should be happening in science classes too. To what extent were the students educated to operate in cooperative learning groups? Questions such as these need to be addressed if we are to make sense of the effects of the cooperative learning strategies on achievement.

The work of Cobb and Wheatley and their colleagues (e.g., Cobb & Wheatley; Cobb, Yackel, Wood, Wheatley, & Merkel) have highlighted the importance of collaboration, negotiation, and consensus building in cooperative learning situations. These appear to be the essential processes that influence sense-making as students engage to solve problems in subjects such as science and mathematics. Clearly there is greater opportunity to negotiate and build consensus when students are arranged in groups. Why then was achievement not facilitated in both units of study in the Lazarowitz et al. study? Did students know what they were to do? What types of achievement measures were used? Were the tasks students were to complete appropriate for cooperative learning? Providing details of the context is crucial if consumers of research are to have confidence that the findings can be applied in their classrooms. What is communicated when cooperative learning strategies are described as being significantly related to achievement in one unit and not significantly related to achievement in another? In the first place a potential consumer probably would want to know why cooperation enhanced learning in one context and did not enhance learning in another. We should not expect any learning strategy to suit all learners in all circumstances. Potential users of research findings can expect to have an understanding of why specific results are obtained.

Studies of teaching and learning ought not to ignore context. The interpretive studies by Contreras and Wilkinson, Treagust, Leggett, and Glasson are fine examples of research which has taken account of the beliefs of teachers and the context in which teaching and learning occurred. Future studies of teaching and learning ought to describe and interpret the practices of teachers and learners and relate them to the specific contexts that apply. The salient features of the context include factors such as the goals to be attained, beliefs and values of teachers and students, and policy stipulations of the school district and state. Variations in such factors inevitably influence what is done in science classrooms and why it is done. Accordingly, studies of teaching and learning ought to describe and interpret what happens in science classrooms, take account of the contextual elements that apply in the classroom, and relate practices to desired outcomes. Studies that advocate one instructional strategy over another without careful analyses of the contextual factors that apply are unlikely to be taken seriously by practitioners or researchers.

Researchers of science teaching and learning are challenged by the continuing problems associated with student learning. Reforms in science teaching and learning are demanded by educational policy makers and the community in general. However, classroom practices remain much the same as they were in the 1950s, and with few exceptions approaches to science teacher education have not altered appreciably since the 1970s. Can research findings inform the practices of science teachers and teacher educators? We certainly hope so. However, researchers must address the extant problems of teaching and learning. We know so much more today about conducting research in classrooms, and applying epistemologies such as radical constructivism (von Glasersfeld, 1987) enable different questions to be posed about the efficacy of specific teaching and learning practices. It is to be hoped that future reviews of teaching methods and strategies will show evidence of strong theoretical underpinnings, use of interpretive methods of inquiry, and a thorough treatment of the contexts in which teaching and learning occur. If this is to be the case the researchers of science classrooms must rise to the challenges embedded in serious attempts to understand teaching and learning.

References

Cobb, P., & Wheatley, G. (1988). Children's initial understandings of ten. Focus on Learning Problems in Mathematics, 10, 10-28.

Cobb, P., Yackel, E., Wood, T., Wheatley, G., & Merkel, G. (1988). Research into practice: Creating a problem solving atmosphere. Arithmetic Teacher, 36(1), 46-47.

Contreras, A. (1988). Constructing subject matter in high school physics: An ethnographic study of three experienced physics teachers. (Doctoral dissertation, Michigan State University, 1988). Dissertation Abstracts International, 49(5), 1045-A.

Lazarowitz, R., Hertz, R.L., Baird, J.H., & Bowlden, V. (1988). Academic achievement and on-task behavior of high school biology students instructed in a cooperative small investigative group. Science Education, 72, 475-487.

Tobin, K., & Espinet, M. (1989). Impediments to change: An application of peer coaching in high school science. Journal of Research in Science Teaching, 26(2), 105-120.

Tobin, K., Kahle, J. B., & Fraser, B.J. (in press). Windows into science classrooms: Problems associated with high level cognitive learning in science. London, England: Falmer Press.

von Glasersfeld, E. (1987). The construction of knowledge. Seaside, CA: The Systems Inquiry Series, Intersystems Publication.

Wilkinson, W. J., Treagust, D. F., Leggett, M., & Glasson, P. (1988). The teaching-learning environment in a student centered physics classroom. Paper presented at the annual meeting of the National Association for Research in Science Teaching, Lake of the Ozarks, MO, April, 1988. (ERIC Document Reproduction Service No. ED 292 619)

6.0 Conceptual Development

Studies included in this chapter are of interest to science educators engaged in research related to conceptual development and learning. Four categories of studies are reviewed: status of conceptual development research (2 studies), descriptive studies of alternative conceptions (21 studies), research on reasoning skills (13 studies), and experimental studies of conceptual change (8 studies). Descriptive studies include 1 focusing on definitions, 6 addressing biological conceptions and 13 physical science conceptions, and 1 on teachers' science conceptions. Studies included in the reasoning skills section address instrumentation (1 study), reasoning and instruction (8 studies), and reasoning and conceptual development (4 studies). The chapter concludes with conceptual change studies — grade one students (1 study), high school students (6 studies), and the impact of conceptual change on students (1 study).

6.1 Research on Conceptual Development

6.11 What is the status of research on conceptual development?

Hashweh noted that many conceptual development studies are characterized by a misfit between the purpose of the study and the methodology used, by diagnosis and conceptualization problems, and by validation problems. It would be helpful, according to Hashweh, if investigators and reviewers of the research differentiate between three kinds of studies: descriptive studies, explanatory studies, and studies that "test" the explanatory studies or that attempt to induce conceptual change. Descriptive studies should aim to identify and describe student preconceptions; explanatory studies to explain conceptual stability and change; and, conceptual change studies to test the explanations offered by explanatory studies. The author reviews descriptive studies of student preconceptions in science, discusses issues related to this type of research, and presents guidelines for conducting descriptive studies. These studies should adhere to a descriptive purpose only and use methodologies suited to the purpose, make a clear distinction between declarative and procedural student knowledge, and include a formal validation phase. Persons reporting the results of descriptive studies of students' science conceptions after completing one or more science courses often note, incorrectly according to Hashweh, that preconceptions are highly resistant to change when, in fact, no attempt was made in the study to alter students' preconceptions. The conclusion justified, according to Hashweh, is that preconceptions persist after instruction not that they are resistant to change.

Watts reviewed alternative frameworks research in science education. Research in the mid-1970s focused on "alternative concepts," "alternative frameworks," "misconceptions," "pre-conceptions," "children's science," and so on. Directing attention to work in physics education led one researcher to conclude that teachers fail alongside their students in rendering error-free answers to conceptual physics questions. In the same year, researchers advised teachers not to dismiss, deride, or decry students' inaccuracies but to view them as opportunities to explore better understandings in science. According to Watts, students harbor unorthodox perceptions about science; these ideas remain intact in the face of normal everyday teaching. The unorthodox view can shape how students make sense of new information, and it can even persist in the face of counter-argument and evidence. Subsequent research revealed that concepts develop as individuals respond to the myriad of everyday influences and experiences around them, giving rise to the phrase "life-world knowledge." Changing alternative conceptions depends on where they fall on a two dimensional matrix, reports Watts. One dimension is defined by how widely the concept is held; the other dimension is characterized by how deeply the concept is rooted. Most difficult to change are science concepts that are deeply rooted, highly individual, and personally constructed. Teachers must first familiarize themselves with a science topic, then encourage students to explore the meaning of select terms and how concepts can link together. Teachers then employ discovery learning to help students personalize scientific models. With the current emphasis on problem-solving, researchers are now probing underlying conceptual processes. Lacking a coherent theory teachers cannot conveniently promote conceptual change. Problem-solving clearly involves constructing a mental model of the solution process in order to achieve a set goal. In addition, problem-solving involves the transfer of cognitive content and skills. Faced with the need for a general theory of concept formation and an understanding of the role mental models play in problem-solving, researchers must continue to conduct descriptive studies of student conceptions in physics. We need to know how students make sense of what they are to learn, according to Watts.

6.2 Descriptive Studies of Alternative Conceptions

6.21 What term best describes students' conceptions?

Using a funnel approach based on successive epistemological arguments, **Abimbola** suggests survey terms that should describe student conceptions in science. Terms such as "erroneous concepts" and "misconceptions" are considered inappropriate based on their relationship to empiricism and revolutionary conceptual change (as described by Thomas Kuhn). Due to the limited application of "alternative frameworks," especially in biology education, "alternative conceptions" is recommended over the term "misconceptions."

6.22 What alternative conceptions do students possess in the biological and physical sciences?

Lawson sought an answer to the question: Does knowledge acquisition in childhood follow spontaneous naive theory construction and cognitive conflict or does learning follow a pattern of gradual accretion of knowledge onto an initially blank slate? Clinical interviews of a kindergartner, a third grader, and a fifth grader were recorded. Choosing three children, one female and two males, from the same family served to control large scale environmental influences. The varied ages of the subjects provided for the comparison of agewise trends in knowledge development. The subjects were questioned on 15 biological topics ranging from photosynthesis to reproduction. An analysis of the children's verbatim statements suggests that knowledge acquisition follows the gradual accretion hypothesis. Their primary source of knowledge is adult authority (e.g., books, television) rather than personal knowledge. Within the biological sciences few students come to class with highly formulated alternate conceptions. In any case, Lawson advocates conceptual change teaching as it provokes students to examine alternative conceptions (i.e., if not their own, then others), thus encouraging the growth of reasoning patterns necessary for testing causal hypotheses.

Griffiths, Thomey, Cooke, and Normore compared three levels of student remediation based on Gagne's hierarchy and misconception research. The key research question was as follows: Does remediation keyed to a student's own misconception better enhance achievement than less specific remediation? Mechanical energy, food webs, and stoichiometry were the concepts taught to 723 high school students. Groups were assigned by stratified random sampling within each classroom based on pretest scores. The content of the tests was appraised by juries made up of subject matter experts and science teachers. Treatments consisted of exercises in remedial booklets inserted between pre- and posttests. Treatment groups included no hierarchy-no misconceptions, hierarchy-no misconceptions, hierarchy and misconceptions, and non-remediation. Although the three experimental treatments resulted in significant pre-post gains in mean scores, no treatment was superior to any other. The authors concluded that direct remediation of specific misconceptions, or the hierarchical treatment with or without use of specific misconceptions, is not superior to simple remediation of test errors following instruction.

Is the size of school enrollment related to the level of student misconceptions in biology? **Simpson and Marek** compared biological understandings of 50 randomly selected students from high schools enrolling 900 or more to 50 randomly selected students attending schools enrolling 150 or less. Students were tested on four biological concepts: diffusion, homeostasis, food production in plants, and classification of plants and animals. Student conceptions and misconceptions were assessed with the Concepts Evaluation Statements, an instrument validated by two science educators, a botany professor, and three high school biology teachers. The written responses of students were judged on five levels of understanding from no response to a sound understanding. Students attending smaller schools disclosed greater misconceptions in the areas of diffusion and homeostasis. No difference was found in the other two areas of biology.

Trowbridge and Mintzes analyzed students' alternative conceptions in animal classification. The study involved 468 students representing fifth grade, eighth grade, tenth grade biology, and college biology students, majors and non-majors. Student performance was tested with an inventory consisting of 19 multiple-choice and 3 free-response items testing animal attributes, diversity, and classification. The inventory was judged to be valid by college biologists, science educators, public school teachers, and a reading specialist. Students in this study subscribed to a highly restricted view of animals, applying the label almost exclusively to vertebrates, especially common mammals. A wide range of alternative conceptions emerged when students were asked to distinguish vertebrates from invertebrates and classify species within the vertebrates. Students across all groups subscribed to a wide range of conceptions, both scientifically acceptable and alternative conceptions. Many alternative conceptions, Trowbridge and Mintzes concluded, develop when students are young and seem to persist into adulthood. Some alternative conceptions yield to instruction more easily than do others.

In a cross-age study, **Westbrook** asked three questions: Do college students exhibit greater understanding of biology concepts than seventh or tenth grade students? What patterns exist among misconceptions held by students across the three levels? Is developmental level a consideration in student understanding of fundamental biology concepts? One hundred students from each of three levels participated in the study. Concept Evaluation Statements (CESs) assessed student understanding of four concepts: diffusion, the cell, homeostasis, and gene function. Two Piagetian-type tasks were used to determine developmental levels. Data analyses revealed that college students were more likely to respond to the CESs and to employ scientific terminology than were the younger students, but the greater frequency of responses did not always mean greater understanding, reports Westbrook. Misconceptions in the college group were frequently due to the misuse of scientific terminology. An increase in student understanding of the cell and homeostasis occurred across age-levels, but no differences occurred in their responses regarding diffusion. Few students responded to the gene function question. Generally, developmental level had no effect on the number of student-held misconceptions for any of the four concepts, the author concludes.

Huang identified and classified 30 biology concepts included in a tenth grade biology textbook for the purpose of investigating student comprehension difficulties, teacher instructional difficulties, and the teachers' perception of student comprehension. Instruments were constructed to assess the three variables. The subjects were intact, tenth grade biology classes along with the teachers, randomly selected from each of 30 public schools in the Republic of China. Huang offered several conclusions: concepts related to genetics and biological structures invisible to the naked eye are difficult for students to comprehend and for teachers to teach; there is a difference between student comprehension levels and the levels of achievement expected by their teachers; and, a positive correlation exists between student comprehension difficulty and teachers' perceptions of instructional difficulty.

To assess children's conceptions of shadows and light, **Feher and Rice** interviewed 40 children ages 8 to 14. A screen, a cross-shaped, fluorescent light source, and two spherical opaque objects was the equipment used in the appraisal process. About 25 % of the children revealed a clear conception of shadows. Most regarded shadows to be material objects that occupy space and are capable of motion. Younger children believed that shadows are present at night and that they belong to the objects that produce them. Although the findings were mixed, all children acknowledged that light is related to shadows. However, light played a dual role for the majority of the children: a dynamic role which caused the object to produce a shadow and a passive role which allowed an observer to see a shadow.

Ault, Novak, and Gowin constructed Vee maps from transcripts of student interviews to track students' progressive differentiation regarding the concept of energy. Putting the energy interviews on the Vee revealed that the subjects' conceptions of energy changed over time, and the action led to several speculations about students' thoughts regarding energy. First, children confused energy with the concepts of force, work, and power. Second, energy is considered to be a fuel-like substance that can be consumed by the motion of the object. Third, children have no understanding of how energy is measured. Finally, concepts of energy seem to persist over time, Ault, Novak, and Gowin noted, even as children acquire new knowledge.

Carrie assessed the understanding of energy acquired by first-year secondary pupils in Scottish schools. The project sought to accomplish three goals: to measure students' understanding of energy concepts, to determine whether this knowledge is acquired during classroom science teaching, and to propose strategies that would maximize effective teaching. Students' knowledge was measured by their responses to two picture tests, containing 28 questions. Students selected examples of energy and energy conversions. To complete a question the student chose from a set of nine pictures; the number of correct responses varied. In addition, the test included two Venn diagram problems, each made up of four questions. Results showed that students are best at recognizing forms of energy which can be directly experienced through familiar objects. Questions about electricity were more difficult than those involving heat, movement, light, or sound. Questions about chemical and potential energy were the most difficult. Strategies recommended by Carrie include having students investigate the relationships of the different forms of energy, introducing each form of energy separately, using card games, and recording student observations in a way that they can better match an energy form with select home appliances.

The beliefs of ninth grade students were investigated by **Haggerty** prior to and during a science unit on heat and temperature. Many of the students' preconceptions persisted in spite of instruction. Teachers did not discredit students' alternative concepts. Rather, the view of science central to classroom instruction was assumed to be correct. The response of many students was to memorize definitions and facts. Some students seemed to distinguish correct answers for school science from their beliefs, giving one response on regular science tests and another on the posttest to this investigation. Scores on regular science tests were significantly related to success on the low-level questions on the posttest, but not to success on high-level questions. Haggerty presumes that the poor showing on higher-level questions may have been due to students' reliance on rote learning. Several factors emerged that seemed to account, in part, for the students' difficulties in handling the classroom view of science: many phenomena were explained in terms of the mechanical energy of the particles of matter; some phenomena went unexplained, and some of the more competent students anticipated explanations; some alternative beliefs were neither identified nor addressed; and, many students seemed unaware of the function of a scientific model.

Mohapatra asked 200 secondary school students 2 questions: What is the second law of reflection? Is it true in the case of reflection of light from a convex mirror? All students responded correctly to the first question; most responded incorrectly to the second question. When interviewed with follow-up questions, students claimed that the law applied only to plane mirrors. The author attributed the students' failure to generalize the concept from plane to curved mirrors to a "misconception" process known as induced incorrect generalization. The findings were generalizable across sociocultural background, economic status, and gender. Mohapatra offered three teaching strategies for correcting student misconceptions illustrated in this study.

Ridgeway investigated the misconceptions held by twelfth grade physics students about the concept of motion. The investigator sought to correct misconceptions by the standard classroom approach to teaching the topic of mechanics. A naturalistic method was chosen. Six free-response questions asked students to predict the behavior of a moving object and to express the prediction in the form of a sketch. Students responded to the questions on curvilinear and rectilinear motions before and after the unit on mechanics. Students had difficulty comprehending drawings accompanying each question; they also misread the questions. Other students poorly coordinated motions within two frames of reference. Following instruction, misconceptions persisted for about 60% of the students on four of the six concepts.

Using clinical interviews **Piburn, Baker, and Treagust** investigated the concepts of gravity held by students enrolled in a physical science class offered at a small private college. Interviews began with open-ended questions, moved to "interview about instances" questions, and ended with a paper and pencil test. Most students grasped some of the relationships of mass and gravity.

The role of students' existing conceptions in mechanics was central to a study conducted by **De Jong and Gunstone**. The study extended over a number of years, at all grade levels, in one all-boys secondary school in Australia. De Jong and Gunstone identified existing conceptions and investigated the process of conceptual change within a classroom setting. Alternative conceptions were found to be common and complex. At the level of individual students, conceptual change was idiosyncratic, complex, and often unpredictable. Some changes involved the spawning of sophisticated alternative conceptions.

Kovacs analyzed the understanding of the nature of physics held by Hungarian and British students. The study was central to a reform of physics curricula in the secondary schools of Hungary where officials looked to Nuffield physics for direction. Student thinking in physics was central to the reform. To test their depth of understanding, physics students were asked to respond to eight practical questions in which the application of physical principles was required, e.g., "When you are walking, you swing your arms. Explain why your arms move like this." About 1100 Hungarian senior secondary school students, both pre- and post-reform, and 100 British counterparts made up the sample. Both physics and literary, non-science students were tested. Their answers ranged from the conservation of angular momentum, the most appropriate response, to inheritance from our ancestors (i.e., monkeys). There were no significant differences between the responses of British and post-reform Hungarian students. There were very different replies from students within the same group. Non-science students did not readily adopt thinking styles expected of individuals who understand the nature of physics. Curriculum innovators bear a heavy responsibility, concluded Kovacs, for the style of thinking that students will adopt who enroll in reformed curricula.

Using four college students enrolled in a first semester general chemistry course, **Feldsine** employed concept mapping to facilitate students' conceptual development and to enlist them as active participants in their own learning. Employing the case study approach, students designed concept maps representing three phases of increasing complexity. Students' independence was varied as well. The students were interviewed during each phase concerning their maps and again three months after the treatment. Four types of data were collected: student-constructed concept maps, taped interviews, day-to-day logs kept by the investigator, and students' answers to quizzes and examinations. Data were analyzed across time for each student and across students to identify common factors. Feldsine reported the following findings: concept mapping incorporated in chemistry can provide the instructor with an assessment of student understanding; concept mapping provides students with a more complete and unified understanding of chemistry; students feel that their concept maps represent their understanding; and, concept maps are valuable means for student evaluations.

Curtis and Millar developed a method for representing students' knowledge and associations. Knowledge describing six basic scientific concepts was classified and coded using information generated by students. The study sought to establish whether Asian children bring to science different conceptualizations of knowledge than their indigenous classmates. Participants included 500 students, in two English schools where Asian languages were spoken by 25% of the students. Students were asked to write freely, e.g., "All I know about . . . (word)." A simple scoring system tallied the number of times each concept occurred in the writings for six concepts: temperature, weight, speed, electric current, power, and pressure. In addition, students were asked to provide information about their use of language. Curtis and Millar reported that existing differences can best be attributed to general fluency in, and familiarity with, the language of instruction, rather than to factors specific to the learning of science.

Schmidt developed new multiple-choice test items in stoichiometry for use with 11th and 12th grade students. Items were constructed to provide one correct and two false answering strategies, to create items with only number ratios for quick mental calculation, and to determine whether pupils adopt false answering strategies on the new items. Results of the project support the need to include items on tests that reflect false and correct strategy application in the same proportion.

Sevenair and Burkett described the statistical analyses used to generate test items for chemistry students that led to a counter-intuitive finding. The item difficulty factor, the percentage of students who respond incorrectly, and the discrimination factor, correlation between student performance on an individual item and performance on the total exam, were calculated for 230 test items. The discrimination factor was calculated using the highest and lowest 27.5% of the students. Top students are expected to answer correctly. Weaker students were expected to guess, responding incorrectly 25% of the time for multiple-choice items that provide students with four response options. Using this intuitive model, predicted values of the discrimination factor were determined and compared to values obtained empirically for a group of 80 students. The data did not support the standard intuitive model. Students who learn nothing guess and respond correctly 25% of the time. Students who learn little, reported Sevenair and Burkett, often employ a thought process that leads to incorrect responses with the chance of getting the item right considerably less than 25%. Their results are supported by Johnstone's hypothesis where working memory is overloaded for those who have learned a little.

6.23 Do teachers harbor the same alternative conceptions as their students?

Research encourages teachers to probe students' knowledge before teaching a concept. Such probing directs the teacher to instruct from the conceptual position of the students. This approach assumes a congruency between the conceptual understanding of students and teachers. **Ameh and Gunstone** explored the validity of this assumption among high school teachers in Nigeria. Two-hundred fifty-one high school teachers were tested on concepts that they had been teaching, and 45 teachers agreed to be interviewed. One-hundred fifty-seven teacher trainees responded to the same test items. Ameh and Gunstone concluded that teachers exhibit the same range of misconceptions as do their students. Teachers use more sophisticated terminology and they manifest fewer alternative conceptions, but no systematic trends attributable to teacher qualifications were noted.

6.3 Research on Reasoning Skills

6.31 Can students' logical thinking abilities be reliably measured?

Bitner-Corvin reported the results of five descriptive studies in which the Group Assessment of Logical Thinking (GALT) test was used. The following questions were asked: how reliably does the GALT measure logical thinking abilities and how well does it predict academic achievement? The reliability coefficients for five samples ranged between .76 and .86. In addition, the individual logical reasoning mode scores and the GALT total score were predictors of academic achievement. The results, according to Bitner-Corvin, support the use of the GALT as a measure of logical thinking.

6.32 To what extent does instruction develop students' reasoning skills?

Blom taught the skills of controlled experimentation to high school biology students classified at one of four cognitive levels. The impact of two instructional treatments on achievement was compared. The Test of Logical Thinking (TOLT) was administered to 127 students in 7 classes taught by 3 teachers. Scores were used to classify the students into one of four Piagetian substages: concrete, transitional, early formal, and fully formal. The treatment, where controlling variables was reduced to eight subskills, was hypothesized to be more effective for transitional students than an alternative method for promoting student achievement in which controlling variables was presented as a holistic endeavor. Two treatment periods were conducted weekly for three weeks. Treatment periods were followed by 42 minutes of related laboratory work. The students were tested one day after each treatment to assess their understanding of the processes used in the laboratory work they had performed. One month later, students were tested on the skills of controlled experimentation and its transfer to a new but related laboratory scenario. All students earned high scores on the composite of the three achievement test scores and on the transfer retention test. However, there were no significant differences between achievement scores of the two treatment groups at any of the four cognitive levels.

Saunders and Jesunathadas tested the effect of familiar and unfamiliar science content upon the proportional reasoning abilities of 76 ninth grade students. Familiar science content was defined as words, processes, and concepts that students encounter informally in their daily lives. Unfamiliar content consisted of words, processes, and concepts found in upper level texts and therefore presumed to be unfamiliar to ninth graders. The instrument, juried by one science and one math educator, consisted of 2 parts: 12 problems, 6 familiar and 6 unfamiliar, requiring proportional reasoning and 5 computation problems and 5 problems not requiring proportional reasoning distributed throughout the test to break up the problem-solving routine. Scores on the proportional reasoning problems were significantly higher on familiar than on unfamiliar science content.

Using sketching and listing tasks, **Winn** tested students for recall. Forty-one students studied five circuit diagrams, either a simplified electric circuit in which elements were labeled with small squares and first letters, e.g., ground is represented with a "G" enclosed in a square, or a diagram using conventional electronic symbols. Important here is the added detail in the latter diagram. High school students unfamiliar with circuitry patterns had to remember the pattern of the elements in a diagram and sketch it from memory (i.e., holistic thinking); or, they had to remember the elements of the circuit and list them in sequence (i.e., analytical thinking). A score was derived for subjects by the accuracy and completeness of their assignments. Students who studied diagrams with electronic symbols performed better on the sequence task and worse on the pattern task than did students who studied the diagrams with squares, whose performance on the two tasks was reversed. Also, requiring students not only to sketch but also to label a diagram did not interfere with their ability to remember patterns. Winn concluded that success in completing tasks that require analytic or holistic thinking depends on the amount of detail provided in the diagram. Furthermore, by varying the amount of detail teachers and other instructional designers can exercise some control over whether students process information holistically or analytically.

Shemesh and Lazarowitz (a) probed the relationship between cognitive ability, age, gender, and school subject preference of 411 Israeli secondary school students. The Video-Taped Group Test (VTGT), based on Lawson's group demonstration test, measured cognitive ability and open-ended responses disclosed the subject matter preferences of students. The findings revealed that the percentage of formal reasoners increased with age. Boys preferred science and technology; girls favored arts and humanities. The preference of males for science and technology, according to Shemesh and Lazarowitz, was attributed to their ability to reason formally at an earlier age and to the masculine image often associated with science, mathematics, and technology.

Grossman tested 30 deaf junior high school students to discern the relationships between background, antecedent cognitive skills, and performance during science inquiry tasks. Antecedent cognitive skills were measured by student performance on tasks related to the perception of pattern/unity relations, periodicity, symmetry, balance, and complementary in the natural environment. Observational tasks typical of those found in elementary school curricula were used to assess performance of science inquiry skills. Performance on the antecedent cognitive skills tests was significantly related to IQ, parental deafness, and performance on the language, science, and reading sections of the Stanford Achievement Test. Furthermore, performance on cognitive skills was significantly related to performance of inquiry skills. In general, Grossman concluded that the results support the contention that the deaf suffer from experiential deprivation which, in turn, hampers subsequent information processing. The findings support the appropriateness of the science inquiry learning model for use with students impaired by deafness.

B. L. Shapiro analyzed the processes by which children fashion personal meaning for their science learnings. Six fifth grade students, three boys and three girls, were studied over a period of six months. Two students demonstrated superior academic ability, two were average, and two were experiencing extreme difficulty in all school endeavors. As the class studied light, the process of concept development of the six subjects was closely observed, and their behavior was recorded. George Kelly's Personal Construct Theory provided the theoretical rationale for the study. Data collection methods used were participant observation, a dialogial approach, attitude of sensitive listening, stimulated video recall, and an adaptation of Kelly's Repertory Grid Test. Themes of personal orientation to learning emerged from the data and were used to examine each child's science learning experiences. Case study reports revealed personal orientation themes related to what students find valuable in science learnings, how they view themselves as learners, and how they interact with the teacher and other learners. Shapiro advised teachers to select science experiences that will help students to become aware of their personal orientations to learning and how they might take greater responsibility for their learning.

In a descriptive study, **Hollon** investigated teachers' beliefs about the learning processes of students. The classroom behavior of 13 seventh grade science teachers was observed as they taught three units: photosynthesis, cellular respiration, and matter cycling units. Teachers were interviewed before the study and at the completion of each unit. Three teacher orientations emerged from the data. First, a conceptual development teacher orientation emphasized learning in which students changed their thinking about important concepts. Curricular goals highlighted the meaningfulness of important science concepts. Here teachers monitored changes in students' scientific thinking. Second, the content understanding teacher orientation underscored assimilation where students added new concepts to existing knowledge. The focal point here was science as an integrated body of knowledge. The importance of science content was clearly communicated, and teachers monitored student understanding of important details. The fact acquisition teacher orientation emphasized memorization. Curricular goals reflected the content embodied in resource materials. Also, a student's emotional state was a teacher concern. Each teacher orientation represented a system of self-reinforcing beliefs based on interaction of teachers' knowledge and beliefs and their judgements about important information and information processing. The first two teacher orientations functioned as open loops, enabling teachers to appraise student thinking on the job. The latter orientation resulted in closed loops where teachers were unable to observe and appraise student thinking.

Eleuterius studied the learning styles of 182 marine scientists. Tested was the relationship of learning style to subdisciplines of marine science, sex, age, education; preferred time of day to learn; and preferred instructional methods. Each subject responded to the Gregorc Style Delineator and the accompanying demographic questions. Concrete sequential learners dominated the sample, followed by concrete random learners. Abstract sequential learners ranked third. Few subjects were abstract random learners. The gender variable went untested due to an insufficient number of female subjects. Neither age nor marine science subdisciplines were related to learning style. Educational level and learning style were related. Learning style and preferred learning time were unrelated. Instructional methods preferred by the subjects, according to Eleuterius, agreed in the main part with Gregorc's assessment of preferences and learner types.

6.33 What relationships exist between reasoning ability and conceptual development?

To overcome misconceptions, according to **Lawson and Thompson**, students must become aware of the scientific conceptions. They must also become adept at generating logical relationships between scientific evidence and alternate conceptions. Because formal operational reasoning is required before students can generate logical relationships, the authors predicted that formal-operational, seventh grade students would hold significantly fewer misconceptions following instruction than would seventh graders classified as concrete-operational. Four well established pretests assessed four predictor variables: formal reasoning ability, mental capacity, verbal intelligence, and field dependence/independence. Following the pretest on each of the four variables, 131 students were instructed for approximately one month on 13 topics involving evolution and genetics. The posttest was an open-ended essay examination. A student's score was the number of misconceptions identified in his/her responses. Misconception scores were compared to student scores on the four predictor variables. Of the four variables tested, reasoning ability was the only variable that consistently and significantly related to the number of misconceptions, reported Lawson and Thompson.

Braathen and Hewson studied a small group of students tutored in college chemistry. The underlying theoretical framework was the constructivist view of learning and Ausubel's theory of meaningful learning. The authors found that students varied in the qualitative changes in their knowledge. Student changes related to the adoption of a meaningful learning set, a predisposition to learn meaningfully, and to the quality and quantity of prior knowledge.

Following the study of chemical change, **Heese** asked first-year high school chemistry students to explain in writing the rusting of an iron nail, the heating of copper in air, and the burning of a wood splint. In addition to written responses, data were collected from the interview of 11 students and an indepth analysis of the learning behavior of 3 students. Data analysis focused on the following: chemical knowledge which included facts and theories; conservation reasoning which related to the students' ability to conserve mass and substance; and, explanatory ideals, or the standards by which experts judge the acceptability of scientific explanations. Only 1 of the 11 students held a chemist's understanding in all three areas, viz., chemical changes are explained in terms of the atomic-molecular theory. The responses of the remaining ten students were classified as transitional or naive, with four students holding naive conceptions across all three topics. The naive students exhibited little chemical knowledge, seldom conserved mass or substance, and seemed oblivious to the concept that the interaction of atoms and molecules formed an acceptable explanation of chemical change. Students explained chemical change by comparing rusting to mold growing on bread. In addition, Heese noted, naive students in this study believe that the difference between their explanations and those of the chemist rests in the chemist's use of scientific vocabulary.

Whether cognitive preference and learning mode interact to affect meaningful learning through concept mapping was the subject of a study conducted by **Okebukola and Jegede**. Nigerian students (n = 135) enrolled in a pre-degree Science Program were assigned to either experimental or control groups based on their cognitive preference. The Biology Cognitive Preference Inventory was used to identify four cognitive preference modes: recall, principles, questioning, and application. Students were taught topics related to photosynthesis via lectures, with experimental subjects working individually or cooperatively being required to construct a concept map at the end of each day's lecture. The findings support the premise that concept mapping fosters meaningful learning. Subjects with preference for principles earned the highest mean score on the measure of meaningful learning, whether working cooperatively or alone.

6.4 Conceptual Change Studies

6.41 Can the misconceptions of students be altered by select instructional methods?

Benbow tested the relative effectiveness of five instructional interventions designed to correct a size-related science misconception among first graders. The misconception chosen was the following: larger magnets are always stronger than smaller magnets. The instructional interventions included: a demonstration lesson, a hands-on lesson, a verbal statements lesson, a demonstration plus verbal statements lesson, and a hands-on lesson plus verbal statements. At the beginning of each magnet lesson, students were exposed to evidence contradicting the misconception. Cognitive conflict was thereby introduced into the treatment by expecting students to compare the magnetic strength of a small, weak, rectangular magnet and a larger and stronger, rectangular magnet. Finally, students interacted with two identical rectangular magnets that exhibited clearly different strengths. The second component of each intervention was the manipulation of iron filings and a magnet to depict lines of magnetic force. Subjects were tested for knowledge three days before the treatment, one day after treatment, and six weeks after treatment. Information at this point was expected to help students in the accommodation of events witnessed earlier in the intervention. Randomly chosen from each treatment group, six subjects were interviewed employing a format based upon Novak's Interview-about-Instances prior to instruction and on two occasions after instruction. Demonstrations were hypothesized to manifest the highest frequency of students with a perfect score on the four misconception-related posttest items. Demonstrations were also hypothesized to manifest the highest retention scores. Analyses of test scores and interview data indicated that a demonstration lesson was no more effective than all remaining treatments in knowledge achievement and retention. However, both treatments involving demonstrations, according to

Benbow, were more effective in correcting the size-related misconception than either hands-on or verbal lessons.

Rogan tested the effect of three variables on acquisition of knowledge about the kinetic theory of heat. The variables included: instruction (conceptual change approach vs. single theory approach), environment (cooperative group vs. individual), and reasoning ability (high vs. low). The effect of the variables was tested in four classes of ninth graders (n = 145) taught by one teacher. Items selected from Erickson's Conceptual Profile Inventory assessed the effects of the treatments on students' support of the kinetic theory, the caloric theory, and children's viewpoint. The results indicate that the instructional factor alone did not significantly affect student support of any of the three frameworks. However, immediately following the treatment a significant decrease in support of the caloric theory was manifested among high reasoning students and those learning alone. Retention data indicated that among low reasoning students, those in the conceptual change approach group also decreased in their support of the caloric theory.

Wells tested an instructional strategy based on the Atkin-Karplus learning cycle and the Hestenes theory of modeling instruction in physics. The strategy utilized an activity-centered laboratory as the mechanism for model development. The Halloun-Hestenes taxonomy of misconceptions in mechanics was chosen to guide the development of the factual knowledge. The effectiveness of the instructional methods was evaluated by pretests and posttests in mechanics. Compared were the pretest-posttest mean gain scores of three high school classes of honors physics students taught by three different methods. Didactic instruction was least effective; inquiry instruction was next; and, structured inquiry instruction was the most effective.

Using the case study method, **Bar-Lavie** designed a learning model for an 11th grade class (n = 63) within the Eilat Eco-Field-Shop (EFS) program at a high school in Israel. Studied were students' conceptual structures in science. The theoretical bases for the study were Gowin's theory of educating, Ausubel-Novak's theory of meaningful learning, and the Sede-Boker version of Environmental Education. Central to the study were three clusters of events which included concept mapping, Gowin's Vee heuristic, and field studies. Data that served as records for analyses included interview transcripts, concept maps, video-tape recordings, and records of student exams and projects. The results, in part, are reviewed here: concept mapping and interviewing are more sensitive and accurate assessments than the objective tests used in the study; Novak and Gowin's strategies are useful for enhancing and evaluating meaningful learning; and, studying in the field favorably influences learning, but it does not replace acquisition of knowledge by students in the classroom.

Testing the effect of concept mapping on achievement was the purpose of a study conducted by **Pankratius.** Students in six intact high school physics classes, all taught by the investigator, served as subjects. Two classes served as the control group and received standard instruction. Four classes were instructed in the design of concept maps for six weeks prior to the physics unit under study. Two classes drafted and submitted concept maps at the conclusion of the unit of physics instruction. The other two classes drafted and submitted concept maps twice, at the onset and at the conclusion of the physics unit. Mapping concepts prior to, during, and following instruction led to greater achievement for this sample of physics students.

Remediating misconceptions through the use of concrete examples was the focus of a study conducted by **D. E. Brown.** Two treatments were compared: science instruction in which bridges analogies are presented sequentially and a more standard method of teaching-by-example. The misconception central to both treatments was the following: static objects are unable to exert forces. Students interacted with a written explanation for the behavior of static objects, one group employing analogies and the other employing examples, e.g., a table pushes up on a book at rest on a table. Responses to an instrument disclosed significantly higher scores on the posttest for the analogy treatment. Interview data unveiled important implications for instruction, according to Brown. In order for students to replace a misconception, they must draw upon and extend existing intuitions rather than memorize counter-intuitive principles. Also, examples that teachers find compelling may not be at all enlightening to the student. In addition, even when an example is compelling to the student, it may not bond to the problem at hand. For an analogy to serve as a bridge in a student's thought process explicit development is needed. Finally, teachers must help students develop models of physical phenomena that Brown characterizes as visualizable, qualitative, and mechanistic.

Guassarsky and Gorodetsky assessed the effect of constrained word association on a change in the cognitive structure of 307 high school students learning chemical equilibrium concepts. The constraints were two-fold: time and specified subject matter. Constrained to one minute for each of the 18 concepts, subjects wrote word associations twice, before and after instruction on chemical equilibrium. Measurement was based upon relatedness coefficients: the number of word associations presented by a subject to each concept and the degree of overlap between a student's two response lists on a certain pair of key concepts. The treatments were two levels of chemistry instruction and a control group. The authors concluded that constrained word associations were useful to monitor the extent and the nature of learning of the equilibrium concept. Cognitive connections between the 18 concepts became stronger and more meaningful. Constrained word associations and the free sorting method generated similar results in cognitive structuring.

6.42 How does instruction targeting conceptual change affect the performance of students during the succeeding year?

Metacognition and constructivist views of learning served as the theoretical bases for a study by **Gunstone**. Here conceptual change was the focus, in particular students' awareness of their conceptual changes. There were three purposes for the study: to investigate the impact of conceptual change on student performance the following school year; to assess students' perceptions of the nature, purpose, and value of the instruction targeting conceptual change; and, to assess the effect of laboratory strategies on conceptual change in a more standard mode of classroom instruction. The participants were 46 students in their tenth year and 110 students the subsequent year, including 28 enrolled the previous year. The treatment employed in year 10 influenced performance the following year. Student perceptions of the conceptual change process varied. The findings support the premise that teachers should encourage students to monitor their learning.

6.5 Invited Commentary — Larry Yore

Reflection on conceptual development research reported in the 1988 synthesis revealed five dimensions, i.e., high degree of interest, limitation of research designs utilized, lack of an integrated theoretic framework, a closed loop of ideas, and questionable instrumentation.

The 44 studies considered in this chapter represent a significant component in science education research. The single largest category of conceptual development studies is the descriptive studies detailing learners' prior knowledge or alternative conceptions. Amongst these studies is an explicit attempt to integrate the alternative conception research into an existing model or to construct unifying models. Some researchers are comparing alternative conceptions recorded in the history of science to those currently found, the effects of discrepant events on motivation and problem focus to the existence of alternative conceptions, and the under-utilized cognitive functioning (assimilation/accommodation) model to the construction of alternative conceptions. These limited efforts will likely reveal promising results.

The advice provided by Hashweh and Watts is well-founded regarding research paradigms to reflect specific problems, their related purposes and their associated limitations. Hashweh's advice regarding clear delineation of problem, purpose, paradigm and product must be followed. Descriptive studies should describe and be limited to clarifying the problem; explanatory studies should explain and be limited to proposing causal relationships; and, verificational studies should test causal hypotheses and expand or refine explanations. This does not endorse a hierarchical value to specific research designs, but rather recognizes the evolutionary nature of present conceptualization of concept development, alternative concepts, and conceptual change. The twenty-one descriptive studies reported in 1988 might well serve as a data base for secondary analyses by which to abduct potential causal relationships of conceptual development and cognitive functioning that might be verified by studies designed to test such relationships.

Hashweh also implies the importance of metacognitive as well as cognitive considerations. Self-appraisal and self-management of cognition are critical dimensions in conceptual development which to date have not received proper consideration in science education research. The declarative, procedural, and conditional knowledge about thinking may be equally important as prior conceptual knowledge. Likewise, the strategic planning, evaluation and regulation of thinking is unexplored in the assimilation and accommodation of conceptual understanding. Gunstone clearly points out the need for such research consideration. Watts' conceptual matrix provides some insights for future research and clarifies the difficulties involved in restructuring widely held alternative conceptions, which are naturally appealing and intuitively logical on the surface. Disconfirming evidence frequently involves abstractions requiring well-developed cognitive operations. Therefore, these alternative conceptions remain unchanged in the minds of non-formal thinkers.

Bransford (1979), Osborne and Wittrock (1983), Holliday (1988), and Jacobs and Paris (1987) outlined an interactive-constructive model of learning that utilizes a generative process and metacognition which has potential for guiding future conceptual development research. This model clearly indicates the importance of metacognition of learning, metacognition of scientific inquiry, conceptual scientific knowledge, and generic thinking. It presents a unified construct on which to develop more sharply focused questions, more sensitive measures, and more insightful conclusions that will be more applicable in the science classroom. Such a paradigm shifts thinking regarding conceptual development research. Time consuming interviews are sensitive but hard to standardize and score. On the other hand, the time efficient paper-pencil examinations have inherent concept label/concept experience problems. The two-part items constructed to assess knowledge and rationale appear to have potential, but still have inherent language problems (Treagust, 1988). The use of concept maps and Vee diagrams are interesting trends that may be productive assessment techniques which reflect people's conceptual development. Standardized scoring procedures will make these techniques more useful. Regardless of the instrument used, concept development research will have limited success in detecting changes or explaining and verifying causal relationships until valid, reliable, sensitive and sensible assessment techniques are developed and employed.

The most exciting results of 1988 are studies confirming the relationship between cognitive development and conceptual understanding and the effects of structured instructional strategies designed to produce conceptual change. Lawson and Thompson's results clearly indicate that improved cognitive development results in fewer unacceptable alternative conceptions. It may be possible that higher cognitive development is reflective of internal thinking, generative processes, or cognitive functioning that is receptive to change, experienced at restructuring, and effective in organizing new information. Therefore, these individuals are able to strategically plan, manage, and regulate their own conceptual change when needed. As they encounter discrepant experiences they restructure or invent schema to accommodate these new data. Less able students require external structures to help them achieve such accommodation. When this internal self-regulation or externally supportive scaffolding is not available the alternate concept remains unchanged. The interesting results reported for structured instructional strategies (guided inquiry, learning cycle, and learning how to learn) directed at conceptual development or metacognition of learning clearly outline a future research trend. The results on the form, sequence, and necessity of the explore, invent, and apply phases in the learning cycle, the teacher structure of guided inquiry, and the content structure of semi-deductive inquiry likely provide additional external structure required to supplement low, internal, self-regulatory structure without hindering the self-regulated learner. The metacognitive-conceptual development effect reported by Bar-Lavie illustrates the potential indirect influence on conceptual development of learning about learning.

References

Bransford, J.D. (1979). Human learning, understanding and remembering. Belmont, CA: Wadsworth.

Holliday, W.G. (1988). Study science information using metacognitive knowledge and experience. A paper presented at the National Association for Research in Science Teaching Annual Meeting. Lake Ozark, MO: April 10-13.

Jacobs, J.E., & Pairs, S.G. (1987). Children's metacognition about reading: Issues in definition, measurement and instruction. Educational Psychologist, 22, 255-278.

Osborne, R.J., & Wittrock, M.C. (1983). Learning Science: A generative process. Science Education, 67, 489-508.

Treagust, D.F. (1988). Development and use of diagnostic tests to evaluate students' misconceptions in science. International Journal of Science Education, 10(2), 159-169.

7.0 Problem Solving

Studies included in this chapter are of interest to science educators investigating problem-solving in science, elementary grades through beginning college courses. Four categories are reviewed: characteristics of expert and novice problem-solvers (9 studies), factors related to success at problem-solving (12 studies), problem-solving among special populations (4 studies), and experiments designed to improve problem-solving skills (9 studies). The characteristics of expert and novice problem-solvers are identified for biology, chemistry, and physics, more specifically the topics of genetics, chemical equilibrium, and mechanics. Success is reported next by probing the nature of problem-solving, the nature of genetics problems, and the cognitive strategies employed when solving problems. The third section explores the problem-solving skills of children, Afro-Americans in chemistry, disadvantaged students in physics, and Westinghouse Science Talent Search winners. This chapter concludes with experiments carried out to improve learners' cognitive abilities, general problem-solving skills, and specific problem-solving skills in chemistry, physics, and elementary school science.

7.1 Characteristics of Experts and Novices

7.11 How do subjects perform when solving genetics problems?

Students' misconceptions and problem-solving difficulties in genetics were identified by **Browning and Lehman**. Prior to the study, 135 elementary education majors completed a seven-week genetics experiment using Drosophila, an approach that emphasized discovery learning over conventional instruction in problem-solving. Students then responded to a computer program that presented four genetics problems, two monohybrid and two dihybrid. They predicted the number and type of each class of offspring. Incorrect responses triggered a step-by-step procedure that directed students to a solution. Analyses of student errors by Browning and Lehman identified three general areas of difficulty: basic computational skills, the determination of gametes, and the inappropriate application of previous learning to new problems. A detailed review of specific errors students committed is included in the report.

Hackling and Lawrence compared the problem-solving performance of three groups of college subjects, using a novice-to-expert continuum. The experts were five university genetics professors; the mid-group consisted of eight third-year biology students; the novices were 15 first-year biology students who had completed the genetics section of a human biology course. The researchers tested participants' performance on three pedigree problems, two with routine solutions and one acceptable answer, and another problem that was non-routine, more difficult, with multiple solutions. Data were gathered using think-aloud protocol procedures. Although novices and experts did not differ in the number of correct solutions, the responses of experts were more complete and more conclusive. More critical cues were recognized and more genotype hypotheses were employed in solutions generated by experts than in solutions generated by the other two groups. First- and third-year students were less rigorous in the falsification of alternative hypotheses.

Smith (a) studied the successful and unsuccessful performances of subjects solving problems in genetics. Participating in the study were 16 undergraduates, 11 graduate students and biology instructors, classified as successful or unsuccessful based on their performance on genetics problems involving pedigree analysis. The responses of subjects were video-recorded during think-aloud interviews. Analyses of the videotaped performances revealed flaws in the problem-solving practices of unsuccessful subjects. The flaws identified by Smith include the following: little or no use of production rules; use of cues noncritical to the solution; inappropriate use of hypotheses; inappropriate conclusions drawn from genetic ratios; faulty use of logic; failure to retrace steps in the decision-making process; making decisions based on opinion or inappropriate evidence; inability to focus on multiple alternatives; deficient understanding of fractions, ratios, and probabilities; and, inappropriate use of the concept of probability.

Observing that Mendelian genetics is an integral part of high school biology courses prompted **Simmons** to study the problem-solving behaviors and concepts employed by experts and novices during interaction with a genetics computer simulation. Thirteen subjects investigated one common genetic trait in cats. Using a think-aloud protocol, each subject's verbal comments and interaction with the simulation were recorded. A learning-cycle organizer served as the framework for the instructional treatment. Patterns of the subjects' problem-solving behaviors and verbalized genetics concepts were analyzed for common and unique characteristics. The data revealed three levels of problem-solving. Success here was expressed by complex patterns of problem-solving sequences and complex use of specific genetics concepts. Verbalizing problem-solving sequences, according to Simmons, may help subjects recognize, analyze, interpret, and evaluate underlying patterns characteristic of specific inheritance traits.

7.12 How do subjects perform when solving chemical equilibrium problems?

G. L. Crosby documented the effects of conventional college instruction on students' qualitative solutions to equilibrium problems in chemistry. Following instruction, 20 students enrolled in general chemistry solved two qualitative, homogeneous equilibrium problems in a think-aloud interview setting. One commonly assigned problem was presented ambiguously, and a second, more novel problem, was presented unambiguously. The solutions of the same problems by five chemistry professors served as an expert model of scientifically-acceptable responses. Actual equilibrium instruction was weighed against the expert model to judge for accuracy and completeness. The expert model was used as a standard to identify unacceptable student propositions. Results indicated that nearly one-quarter of the students arrived at correct answers for the wrong reasons. Although problem-solving instruction was accurate, textbook and lecture instruction failed to identify and apply the concepts needed to solve qualitative problems. Crosby calls for more qualitative problem-solving in chemistry of the type tested here.

7.13 How do subjects perform when solving mechanics problems?

Employing the rule assessment procedure, **Maloney** analyzed the prediction procedures novices use to solve problems in physics. Sixty-four undergraduates who had not taken a college physics course responded to 12 task sets, 6 depicting a sphere thrown from a cliff and 6 depicting a horizontal stream of liquid. Three variable pairs of physics concepts were featured in the study: mass and speed; mass and height; and, speed and height. Half of the subjects were directed to consider air resistance in their predictions of spheres and streams; the other half were directed to ignore it. In addition to their predictions for the physics problems, subjects shared verbally with the investigator their rules or procedures for the choice of solutions. Maloney reports that most novices work from rules. Although rule usage was planned to be similar across both the spheres and streams problems, 7 percent of the subjects used the same rule for two or fewer of the six task set pairs. Males and females employed different rules on 6 of the 12 task sets. High school physics influenced novices' performance on 2 of the 12 task sets. The students' patterns for rule usage were the same whether they were instructed to consider or to ignore air resistance.

Hardiman, Dufresne, and Mestre investigated the relationship between problem-solving ability and the principles used to decide whether two classical mechanics problems could be solved similarly. In the first of two experiments, experts and novices were compared on a similarity-judgement task. The subjects were experts, 8 PhD physicists and 2 advanced physics graduate students, and novices, 45 undergraduates who earned a grade of "B" or better on the first semester of a classical mechanics course. Experts were prone to rely on the deep structure to reach a solution. The presence of surface feature similarity adversely affected performance here. Novices depended principally on surface features, but under some conditions they were adept at employing the problems' deep structure option. In the second experiment, 44 novices prone to employ different types of reasoning in making solution-similarity judgements were compared. Novices who relied predominantly on surface features differed from novices who made greater use of principles. The latter group of students were inclined to categorize problems similarly to experts, as well as to score higher on problem-solving. The results suggest, according to Hardiman, Dufresne, and Mestre, that principles play a fundamental role in the organization of conceptual and procedural knowledge for good problem-solvers at all levels.

Knowledge elicitation via computer programming was employed by **Law** to explore students' intuitive ideas about motion. The subjects, 17 year-old, sixth-form science students and 14 year-old, third-form students, were asked to write expert systems programs about motion. The interactions of programing with the subjects' intuitive knowledge of motion were observed. The 17 year-old students had just completed a 2-year physics course, and the 14 year-old students had received no formal instruction. PROLOG was the language chosen. Preliminary analyses suggest that one can verify a student's conceptual framework regarding motion using PROLOG. In addition, intuitive ideas on motion are not compartmentalized alongside learned physics concepts, but rather they become woven into a personalized, inate way of viewing the world of motion. The nature of conceptual integration here depends principally on the degree of structure within a student's knowledge base about motion.

The purpose of **Dufresne's** study was to explore the similarities among experts, as well as good and poor novice problem-solvers. A similarity-judgement task was presented to each subject with two problems to compare, a model and a comparison problem. Subjects were expected to report whether the same approach would be used to solve both problems and to offer a rationale to support each decision. By varying the surface feature and deep-structure similarity of both types of problems one can assess the relative importance of the two factors to problem categorization. The problems were given to 7 expert physicists and 46 novices who had just completed an introductory physics course. Results revealed that physics principles direct the reasoning of experts almost exclusively; novices differed from experts and from each other in the degree to which they used those principles; the criteria employed to classify a problem were related to problem-solving proficiency; and, there was a significant positive correlation between frequency of attempts to reason with principles and problem-solving scores, even when mathematics proficiency was held constant. In a second experiment, Dufresne sought ways to help novices become better problem-solvers by precipitating the formation of expert-like knowledge structures and by encouraging them to use a more expert-like problem-solving approach. Subjects solved 25 classical mechanics problems over five, one-hour sessions. A menu-driven, computer-based environment (Hierarchical Analysis Tool or HAT) regulated the problem-solving activities of novices. Experimental group subjects used the HAT program. Two comparison groups served as controls, one using the textbook as a resource; the other was a novice-like, computer-based environment which offered subjects 178 equations that could be searched via surface terminology. The effectiveness of the three treatments was compared in three areas: problem categorization, explanations of the physical situation, and problem-solving ability. Results favored the HAT treatment on all outcomes except problem-solving, with the HAT and textbook groups performing similarly.

7.2 Factors Related to Success at Problem-Solving

7.21 What are the unique attributes to problem-solving?

Comparisons of expert and novice problem-solving attributes in physics have helped to identify some of the key elements of expert behavior, report **Schultz and Lochhead**, but there is considerable debate as to whether these characteristics are specific to physics or exportable to other fields. At least three attributes frequently observed in physics "experts" seem to have application to other fields: organizing quantitative calculations through an understanding of qualitative relations; organizing one's knowledge according to principles selected to fit the current problem's anticipated solution; and, evaluating the probable validity of a model through use of an analogy or a chain of analogies. Schultz and Lochhead conclude that expert knowledge appears to be a complex network of interconnected concepts, presenting experts with many paths to correct solutions.

7.22 What is the nature of genetics problems?

Genetics problems have been traditionally categorized by inheritance patterns: simple dominance, codominance, and multiple alleles. **Stewart** presented an alternative typology of genetics problems based on the type of thinking involved in seeking a solution. Genetics problems can be classified as those requiring cause-to-effect thinking and those requiring effect-to-cause thinking. A typology based on the thinking skills used by problem-solvers, according to Stewart, should more readily increase conceptual knowledge, promote content-independent and content-specific heuristics, and elevate the understanding of the nature of science.

7.23 What cognitive strategies are utilized when solving problems?

Bloom identified the strategies students apply in defining a problem and seeking a solution. Four high school students enrolled in biology were asked to solve a series of biological identification problems. Data were obtained by the think-aloud technique and subjected to protocol analysis. Five major heuristics were evident in the protocols of the four students: three strategic heuristics (trial-and-error, generate-and-test, and inferential elaboration) and two search heuristics (random searching and focused searching). Of the three strategic heuristics, generate-and-test and inferential elaboration appeared to be most effective for developing problem representations and reaching correct solutions. Of the two search heuristics, focused searching was most effective in making associations with information in prior knowledge and in generating accurate conjectures. Four primary, manipulative strategies (inferring, testing validity of conjectures and inferences, and elaborative sequencing) and two secondary attention-focusing strategies (focusing comments and status comments) were apparent in the protocols. Although both repetition and inferring kept information accessible for working memory, inferring resulted in the formation of more elaborate problem representations. Testing the validity of conjectures and inferences provided an effective means of directing student thinking toward an acceptable solution.

Costello investigated the role of disjunctive reasoning in solving genetics problems. The verbal protocols provided by subjects during problem-solving and interview sessions rendered information on the nature and frequency of use of the disjunction connective. Subjects with lower scores were prone to overlook the problem's underlying structure, were quick to apply memorized ratios, assigned incorrect symbols, manipulated symbols in keeping with their misconceptions, experienced difficulty applying Mendelian principles in the selection of symbols, separating the symbols to form gametes, and recombining the symbols to form zygotes. Their search strategies were also weaker than the better problem-solvers who were prone to exploit representative systems. As the use of the disjunction connective increased during the subjects' problem-solving and interview sessions, so did their total score on the genetics problems. Problem-solving behaviors, concludes Costello, reflected the subject's ability to establish and manipulate logical relations while using the disjunction and their ability to encode and combine specific knowledge using these relations.

Smith (b) explored the mental schemes employed by experts and novices for organizing their knowledge. Their categorization schemes were scrutinized as they responded to a diverse group of genetics problems. Participants included 7 biology faculty members, 8 certified genetic counselors, and 26 college students. Subjects organized a set of 28 genetics problems based on their solution procedure. Their schemes were recounted in writing. Subjects were classified according to their success on four moderately difficult genetics problems. Successful subjects, both faculty and students, organized problems in a format that might match the chapter headings in a standard genetics text. The organizational schemes of genetic counselors differed from those of faculty members. Counselors and students emphasized the knowns and unknowns in problems. In addition, the counselors emphasized solution procedures. Based on these findings, Smith concluded that mental schemes for organizing knowledge and procedures used by different types of experts in a given discipline are not necessarily designed along abstract-conceptual lines.

Staver and Jacks investigated the influence of cognitive reasoning level, cognitive restructuring ability, disembedding ability, working memory capacity, and prior knowledge on high school students' performance when balancing chemical equations by inspection. Prior to a four-day treatment period on balancing equations, 83 high school chemistry students were tested on the first four variables (cited above) using instruments well established in the literature. Two tests on chemical formulas and equations, judged for content validity by two chemistry teachers, tested prior knowledge. Performance was assessed by a test requiring students to balance 15 chemistry equations, an instrument designed by Staver and Jacks and judged to be valid by two chemistry teachers. When only prior knowledge was considered, student understanding of chemical formulas influenced performance. When prior knowledge, working memory, and restructuring ability were considered, only the restructuring variable influenced performance. Working memory capacity did not significantly influence overall performance — with select posttest equations excepted. Prior knowledge and the ability to restructure also influenced performance on balancing select chemical equations included on the posttest.

M-power refers to mental concentration and M-demand is the amount of information processing required of a task. An increase or decrease in M-demand required to solve a problem can be expected to affect student performance. **Niaz** (a) investigated the effect of an increase in M-demand on the performance of chemistry students having different functional M capacities, cognitive styles, and formal operational reasoning patterns. The three predictor variables were measured with instruments well established in the literature. Eight chemistry problems were selected with the same logical structure but classified in pairs as either M-demand 6 or M-demand 7, a range that represented a small variation in M-demand. The chemistry problems and tests representing the predictor variables were administered to 115 college students. Manipulating M-demand classified students into one of four groups along a continuum: perfect scorers, persons scoring higher on M-demand 7 than on M-demand 6 problems, persons scoring higher on M-demand 6 than M-demand 7 problems, and those scoring zero. Perfect scorers made the highest scores on all predictor variables on three pairs of chemistry problems (no perfect scores were made on the fourth pair). The performance of one group of subjects, the third group, was lower after the increase of M-demand in three of the four pairs of chemistry problems. According to Niaz, even small increases in M-demand can lead to working memory overload, as a consequence of a poor capacity to mobilize M-power.

Carter assessed the role beliefs serve to limit strategy selection during problem solving in chemistry. Data were gathered during clinical interviews. Nine students were interviewed throughout the first semester of a year-long chemistry course for science and engineering majors. Students were presented with traditional and nontraditional problems in chemistry and non-chemistry settings. Probed here were student beliefs about problem-solving in chemistry, especially establishing a context for the task. Beliefs examined included the following: the nature of chemistry; source of knowledge; roles of teachers and students; problem-solving; the roles of authority, creativity, and algorithms in chemistry; one's chemistry ability; and, how to study chemistry. Results disclosed that beliefs influence several factors: the selection of and the degree to which students rely upon algorithms; student willingness to examine concepts and to consider alternate solutions; decisions as to when a problem is solved; the degree of evaluation; one's confidence in a solution; perceptions of what tasks and problems are "fair" or solvable; and, basic approaches to learning and studying chemistry.

Pirkle and Pallrand explored the effects of cognitive style on the way novice problem-solvers perceive and process information. In their study, 39 junior high school students, identified as field-dependent or field-independent, were individually questioned about their understanding of the effect of gravity on vertical, horizontal, and projectile motion. Students were given the opportunity to compare or verify their responses with information presented graphically on a computer monitor. Questions were composed and then organized to access increasingly more abstract levels of knowledge. Student responses were qualitatively analyzed and grouped according to their progression through the pattern-matching phase, transformation phase, and post-experimental phase. The students were tested with the Group Embedded Figures Test (GEFT). Pirkle and Pallrand found that success on the transformation phase of the problem-solving task was related to high performance on the GEFT.

The development of proportional reasoning strategies was the subject of **Roth's** study. A priori hypotheses linked the amount of practice needed to induce problem-solving strategies to the cognitive variables of M-space, field-dependence, and numerical inductive reasoning ability. The subjects were students enrolled in a university-level physical science course for non-science majors. Ratio and proportion problems were designed at six different levels in two content areas and were presented to the subjects via a personal computer. Subjects were audio-taped as they deliberated aloud, and the strategies used to solve the problems were assessed. Results of data analyses disclosed that M-capacity, degree of field-dependence, and numerical inductive reasoning ability did not predict the amount of practice needed by concrete-operational college students until they induced the proportionality scheme. The degree of field-dependence did not predict the ability to transfer problem-solving strategies to a different context, or to replicate such strategies after they had led previously to incorrect solutions. Numerical inductive reasoning ability predicted the amount of practice needed by concrete operational college students to induce the product-moment rule on balance beam problems. Results of the study, according to Roth, suggest that a short-term, storage span correlates highly with such attributes of learning as transfer of reasoning strategies to different contexts and response pattern after feedback.

Pallrand investigated the knowledge representations of novice physics problem-solvers, ten master's students in elementary education. The investigation focused on the following concerns: how naive subjects organize and represent knowledge when solving problems; how previous experience of a novice is employed in problem-solving; the kinds of information sought and overlooked by novices; the kinds of strategies novices employ; and, the cognitive abilities associated with the more successful, novice problem-solver. The problem presented a sequence of phases, each built upon the previous one. The solution process required the subject to restructure the problem elements for use in a new and extended environment. Projectile motion problems were presented to subjects via a clinical interview. Once the subject had presented his or her verbal view of the problem, the response was graphically simulated on the computer screen. The subject then compared his or her interpretation of events with that generated by the computer. In general, Pallrand reports that successful subjects are those who are adept at constructing, adjusting or redefining representations.

Chi and Bassok assessed how students learn to solve simple mechanics problems; what is learned when they study examples in the text; and, how they use knowledge gained from the examples to solve problems. Initially university students studied measurement, vectors, and motion in one dimension until they could solve declarative, qualitative, and quantitative problems. Next, students studied particle dynamics. Students examined three worked-out examples, talking aloud as they analyzed each one. Their sessions were taped. Students then solved two main sets of problems. The first set consisted of 12 problems, 4 for each of the 3 types of examples, and the second set was more difficult to solve. Here, protocols were also recorded. Knowledge pretests and posttests were administered to the subjects. More and less successful students differed in their process of problem-solving. Successful students manifested more quality in their explanations.

7.3 Success Among Members of Special Populations

7.31 Are members of special populations differentially effective at problem-solving?

Martin analyzed the process of systematic thinking among children. More specifically, the investigator probed the process teachers might consider that would integrate children's everyday experience with science and problem-solving. How might we define a child's problem and what might children consider a solution? To explore the systematic thinking of children, teachers conducted discussions centering on "The Voyage of the Mimi" followed by specific questions. Videotaped and transcribed discussions served as a data base. The investigation unveiled different models of children's thinking, suggesting that their definition of a science problem varied. Children, Martin concluded, need to function beyond surface explanations of events in order to promote adequate understandings of the processes of problem-solving.

The problem-solving strategies of Afro-American students were examined by **Alick and Atwater**. The participants were 30 students, both Caucasian and Afro-American, enrolled in general college chemistry courses. Following instruction on stoichiometry and methods for solving stoichiometric problems, students were expected to solve six problems employing the think-aloud method. Here successful problem solvers were prone to include inductive, deductive, or proportional reasoning in their solutions. Unsuccessful students committed structural errors, such as misapplying the moles to grams conversion. The study revealed no differences between Caucasian and Afro-American students in cognitive ability or the strategies exercised to solve stoichiometric problems.

Mehl studied the cognitive difficulties experienced by first-year university physics students in South Africa, characterized as disadvantaged in terms of their preparation in science. The investigation sought to identify the cognitive reasons for their poor performance and to design instructional materials to better enable students to achieve success in solving physics problems. Thirty person-to-person interviews were conducted where students attempted to solve kinematics problems as the interviewer looked on. Analyses of the interview data disclosed that students displayed a regularity in the types of errors committed. Students also demonstrated significant cognitive difficulties in analyzing the data presented in the problems. A paper-and-pencil test examined whether students, after instruction, displayed any systematic approach in their use of Newton's laws to solve physics problems. Scores on the test when administered to 86 first-year physics students suggested that traditional physics instruction did little to help disadvantaged students employ Newton's laws systematically in the solution of physics problems. Instructional materials were developed to assist students using an algorithmic approach to problem-solving. Booklets were designed to teach cognitive operations central to this study. An experimental group using the new materials recorded significant gains in scores on quarterly examinations, over a control group which received conventional physics instruction.

Factors associated with problem finding, the process involved in finding a research problem, was central to a study conducted by **Subotnik.** The long range purpose of the study was to gather data that could predict success in science. From the initial pool of 147 winners of the 1983 Westinghouse Science Talent Search winner group, 57 subjects were selected, persons who attested that their research question was selected independent of the suggestions of others. Using Guilford's Structure of Intellect Model, 31 factors representing the creative process of scientific discovery were chosen as the bases for a questionnaire. Investigated was the relationship between the Structure of Intellect Model and problem-finding. Subjects were asked to rank the five factors which best described their process of choosing a research question. Results revealed the following five factors: convergent production of semantic implications, evaluation of semantic implications, cognition of semantic systems, convergent production of semantic transformations, and cognition of symbolic systems. Subotnik concluded that problem-finding here shares the same intellectual constructs as the more global scientific research process.

7.4 Experiments Designed to Improve Problem-Solving Skills

7.41 What can be done to improve learners' cognitive abilities?

Rose tested the effectiveness of an experimental treatment on the proportional thinking of tenth grade remedial biology students. The experimental group received lab-based instruction which taught the strategy of proportional thinking directly, as well as the metacognitive processes of planning and self-correction; control group students experienced traditional laboratory instruction. Each group consisted of a nonrandomly-assigned class of 11 students. A test on proportional thinking was administered as a pretest, posttest, and delayed posttest. Group differences were found, favoring direct instruction on proportional thinking and metacognitive strategies on the immediate posttest but not on the delayed posttest.

The effect of manipulating perceptual field factors on proportional reasoning ability was central to an investigation conducted by **Niaz** (b). The participants were 113 undergraduate science majors enrolled in a chemistry course. Subjects were pretested to determine their degree of field-dependence/field-independence using the Group Embedded Figures Test (GEFT). Performance on proportional reasoning tasks was assessed with four test items adapted from the Lawson Test of Formal Reasoning. Perceptual field was altered by reducing the numerical value of the quantities that subjects were presented with in each of the four tasks. Evidence supported the hypothesis that perceptual field demands affect student performance on proportional reasoning tasks. The correlation coefficients between the GEFT and the four items of proportional reasoning remained significant before and after the manipulation of the perceptual field factor.

Shemesh and Lazarowitz (b) studied the effects of Piagetian-like tasks on task performance by different age-group students. The tasks were part of a validated test that measures students' reasoning skills in six cognitive operations: conservation, proportions, control of variables, probability, combinations, and correlations. Subjects (n = 556) were enrolled in the 7th, 8th, 9th, or 12th grade in one of two urban schools. Experiment 1 tested the effect of the method of task presentation, video-taped demonstrations versus paper-and-pencil tasks with illustrations. Experiment 2 tested the effect of questionnaire format, multiple-choice versus short essay questions, and Experiment 3 tested the effect of numerical content, integer ratio versus non-integer ratio, on different age-group students' responses. Data analyses indicated that method of task presentation had an effect only on younger students' performance, in this case favoring the video-taped demonstrations. Numerical content had an effect on the majority of students at all levels favoring integer ratio. Formal reasoners were indifferent to numerical content format.

7.42 How can problem-solving skills be improved?

A group of 15 racially-diverse high school students, nine boys and six girls, participated in an intensive 4-week summer project reported by **Zuman and Weaver**. All students had completed one beginning algebra course before entering the program. The project's goals were to develop science and mathematics curricula based on the principles of systems dynamics, a model designed to improve students' problem-solving abilities by introducing them to modeling software and concepts of systems thinking. Students studied levels and rates, causal-loop diagrams, feedback, exponential growth, exponential decay, goal-seeking behavior, s-shaped behavior, and oscillating behavior. Real-life problems were modeled: population growth, bank balances, temperature cooling, capacitor discharging, city growth, and predator-prey relationships. Project evaluation consisted of pre- and posttesting, observation, background questionnaire, and student interviews. Data generated by all questions in the categories tested disclosed a significant gain from pre- to posttest. Students who could succeed intuitively in problem-solving, reported Zuman and Weaver, often had difficulty handling a more precise, mathematical approach.

Heyworth compared the mental representation of knowledge for novice and expert students in high school chemistry. Central to the study was the conceptual understanding and problem-solving skills of tenth and eleventh grade students in volumetric analysis. Using pencil-and-paper tests together with task-based interviews data were gathered on problem-solving procedures, errors and strategies, conceptual knowledge, misconceptions, and knowledge organization. An intervention was designed for novice students to overcome observed errors and misconceptions. Conceptual knowledge of expert students was congruent with scientific knowledge structures in terms of accuracy, organization, and integration with problem-solving procedures. In contrast, novices comprehended technical terms poorly; abstract concepts were frequently linked to visual features of phenomena; and, knowledge often conflicted. Procedural knowledge often operated independently of underlying knowledge precluding novices from explaining solutions qualitatively. Instruction in conceptual knowledge mapped onto procedural knowledge overcame most errors and misconceptions. Problem-solving manifested an increased use of strategies and representations practiced by experts. Heyworth concludes that conceptual understanding is a prerequisite to effective problem-solving. Proficiency with basic problems before approaching more complex problems was encouraged.

Martens reported on a multi-case study of the behavior of three elementary school teachers switching from teaching science as dispensing content to an approach encouraging problem-solving. The researcher was a mentor and change agent. Data collection spanned a year using classroom observations, interviews, and documentary analyses. The factors that affected teacher change included the following: the presence or absence of environmental factors such as administrative support and flexibility; available science materials; a school philosophy encouraging full development of student potential; prior and concurrent outside-of-school experiences encouraging independence; parental support; and, teacher status. The following personal factors influenced teachers' classroom practice: background in science; ability to see interdisciplinary teaching possibilities; organizational ability; regard for the individual student's ideas; need to maintain control over student activities and thinking; personal reflectivity; regard for other teachers' intelligence and experience; emphasis on success; need to "cover" a textbook; understanding of the relationship of science content and problem-solving; and, a general openness to change. Possessing a unique combination of these factors, each teacher handled problem-solving differently. In a self-analysis, the researcher/mentor reported deeply embedded prescriptive tendencies.

7.43 How can subject-specific problem-solving skills be improved?

Osmasta and Lunetta tested the effect of an instructional strategy where local and global approaches to physics teaching served as the experimental treatment. Local approaches involve numeric solutions; global approaches entail generalizations where equations are stated, then plotted on graphs and interpreted. Rather than the common dichotomous treatment of local and global approaches, here physics instruction interrelated the two teaching strategies. Conventional physics teaching served as the control. Both instructors taught an experimental and a control group. Mathematical reasoning was assessed prior to treatment, and the posttests were attitude toward physics, attitude toward the calculator, and physics achievement, which consisted of tests containing items representing both local and global problem-solving. Subjects in the experimental group performed better on local and global achievement than did subjects in the control group. Subjects with higher mathematical reasoning ability scored better on both achievement tests than did low ability subjects. No group differences were disclosed on attitude toward physics; both treatment groups were very positive. An interaction effect was reported between calculator attitudes and treatment, instructor, and reasoning ability. Osmasta and Lunetta suggest that physics instructors who interrelate local and global problems can enhance conceptual understanding and certain problem-solving skills.

The purpose of **Amigues** study was to investigate the influence of peer interaction on 10th grade students' comprehension and production of electrical diagrams. Fifty-eight students were randomly-assigned to four groups: two phases of the task (comprehension and production of electrical diagrams) and alone or in pairs. The effect of interaction was assessed for each of the tasks with individual posttests. A group of 16 additional students were divided into dyads for both tasks, and their performance was recorded on videotape. Results attested that sociocognitive interaction has a positive effect on student performance. By destabilizing the conventional problem-solving strategies employed by students, social interaction served as a source of cognitive growth. Qualitative analysis of the group functioning in pairs suggested that peer interaction facilitates the use of metacognitive mechanisms, such as self-regulation and self-monitoring, which in turn improves the representational skills of students.

Will skills in proportional reasoning taught before instruction in three physical science problems promote transfer of learning among the problems? **Farrell** sought answers to that question among 115 eighth grade students. The treatment materials were self-instructional packets that included explanations, diagrams, drawings, and problems on the following topics: the balance beam, inclined plane, and hydraulic lift. Subjects were pre- and posttested, with a random-half of each treatment group receiving additional instruction in fractional proportions. Students instructed in proportionality manifested greater learning than did uninstructed subjects. Transfer was not affected by the topic of the instructional packet.

7.5 Invited Commentary — Joe Krajcik

Problem-solving is an important component of everyday life. The ability to solve problems determines how successful an individual will be at finding solutions to challenges in life. Problem-solving in any domain is a very complex process involving problem recognition, defining the problem, generating possible strategies to solve the problem, implementing a strategy, and evaluating to see if the problem has been successfully resolved. The overall process involves the integration of conceptual knowledge and strategic knowledge. It it not surprising, therefore, that many individuals have a difficult time solving problems. Moreover, teachers find problem-solving difficult to teach. Continued research in problem-solving and implementation of this research in instructional settings can help learners become more effective problem-solvers.

Problem-solving research in science education in 1988 shows several fruitful trends. The authors of these works have helped develop our understandings of how learners solve problems in different domains and how to improve problem-solving. There are areas in problem-solving, however, that need more focused attention. This commentary is written in the spirit of improving the problem-solving research in science education.

As science education researchers continue to examine problem-solving, two distinct problem situations have emerged. One type of problem-solving involved students solving exercises which have an algorithmic solution. I refer to this type of problem-solving as exercise–solving. In the other type students solve problems which require them to define the problem, design a strategy for solving the problem, implement those strategies to solve the problem, and then evaluate the solution to determine if the problem was resolved. I will refer to this second type of problem-solving as complex problem-solving. Several studies appeared to have students solving exercises (for example: Browning and Lehman; Niaz; Omasta & Lunetta; Staver & Jacks). In exercise–solving students find solutions to word problems by applying algorithmic techniques.

Exercise solving can be contrasted to solving complex problems. In complex problem-solving students cannot find immediately solutions, apply qualitative understandings, may or may not use algorithms, and spend a greater length of time trying to solve one or two complex problems. As we continue our study of problem–solving, we want to engage students in complex problem-solving rather than finding solutions that have algorithmic techniques. Some examples from the 1988 research involving complex problem-solving include Crosby; Simmons; and Smith. Students in the Crosby study solved two qualitative, homogeneous equilibrium problems using a think-aloud procedure. In the Simmons study, students used computer simulations to determine the genotype of the parents from the phenotype of offspring. The subjects in the Simmons study spent from 15 minutes to two and half hours solving a single problem.

When reading manuscripts, researchers, educators, students, and others need to know which type of problem-solving was examined. One very useful technique is found in Smith (a). He included his problem-solving items as part of the manuscript, allowing others to examine the problems.

Problem-solving research has traditionally compared the problem-solving performance of experts to the performance of novices. The research in 1988 sees this trend continuing (Crosby; Hackling & Lawrence; Hardiman, Dufresne, & Mestre; Simmons; Smith; Stewart). These studies involved comparing the problem-solving performance of professors in the knowledge domain with the problem-solving performance of introductory college or high school students. Crosby's study illustrates this method. Here, the performance of 20 students enrolled in general college chemistry was compared to the performance of five chemistry professors. This method of research has given us much useful information. Hardiman, Dufresne, and Mestre provided additional verification that experts rely on deep structures to reach solutions, whereas novices rely on surface features. Expert-novice studies assume that experts have well integrated conceptual understanding of the domain; however, experts differ in their conceptual development and in their problem-solving performance. Simmons' study illustrated how experts in genetics differ in problem-solving. The assumption that individuals classified as experts have integrated conceptual understanding may be questionable. Researchers need to examine more carefully the problem-solving behaviors of individuals who have conceptual understanding of a domain with the problem-solving behaviors of individuals who have incomplete conceptual understanding of the same domain. Heyworth examined the conceptual knowledge of students and found it to be a determining factor in problem-solving. More studies assessing the conceptual knowledge of the learner on problem-solving performance in a variety of domains need to occur. For instance, Hardiman, Dufresne, and Mestre found that novices who made greater use of principles compared to novices who made use of surface features differed in the problem-solving performance.

The use of think-aloud methodologies can provide information to map out the conceptual understanding and problem-solving strategies of learners. The 1988 problem-solving research includes several examples of this fruitful methodology including Crosby; Hackling & Lawrence; Simmons; and Smith. The use of think-aloud methodologies and other qualitative techniques such as clinical interviews and videotapes of students engaged in problem-solving activities (Martin) are extremely time demanding methodologies; however, these techniques provide valuable information regarding the learners conceptual and strategic understandings. As stated previously, problem-solving is a complex process and researchers should not expect to measure it with short and easy-to-use measures. The pretest/posttest design of the control/treatment design provides useful information if the researcher wants to determine the impact of a treatment on problem-solving performance; however, much information regarding the conceptual understanding and the strategic understanding of learners is lost by these designs. Zuman and Weaver examined the influence of computer modeling tools that enabled students to solve problems in the natural and social sciences that normally would involve the use of calculus. Apparently, this microcomputer tool encouraged students to make predictions, collect data, and make computer models to test their predictions. These are all important steps in the problem-solving process which can foster the development of conceptual knowledge; observing the behaviors of students as they use this type of tool software provides opportunities to determine if the use of software tools do promote the use of problem-solving processes.

Browning and Lehman used a computer program to determine student problem-solving difficulties in genetics. They presented some interesting data that indicate the usefulness of the methodology. However, think-aloud techniques provide rich data sources that can be lost by the computer methodology. Although the computer can complement more in-depth methodologies such as the think-aloud method, it should not be used to replace other data gathering techniques.

Several studies investigated the impact of intervening instructional techniques on problem-solving performance (Amigues; Omasta & Lunetta; Simmons; Zuman & Weaver). The research performed by Osmasta and Lunetta appears to be a start on how students can develop better conceptual understanding and problem-solving skills in the physics classroom. Amigues investigated the influence of peer interaction. Examining the impact of instructional techniques on problem-solving performance is a vital area of research which needs further investigation. Smith (a) mentioned several other possible strategies to improve problem-solving including encouraging students to think aloud, emphasizing the process of problem-solving, and modeling problem-solving. Researchers need to examine the impact of these and other instructional strategies. We might also examine the impact of instructional methods. For instance, what is the impact of conceptual change teaching on problem-solving performance? As in the Zuman and Weaver study, researchers also need to examine the impact of other microcomputer tools that purport to promote problem-solving. The immediate graphical feedback students receive as they perform an investigation using Microcomputer Based Laboratories (MBL) has led many science educators to speculate that MBL can promote the asking of "What if" questions and the designing of new investigations. Such problem-solving behavior can have a substantial impact on the development of conceptual understanding. These claims have important ramifications for the teaching of science and need systematic investigation.

Researchers also need to investigate the impact of instructional strategies on problem-solving performance over prolonged periods of time. What happens to the problem-solving performance of learners if problem-solving is modeled beginning in the elementary grades?

As stated previously, a central feature of problem-solving is asking and refining questions; that is, finding a problem. Subotnik examined the factors associated with problem finding. More research of this nature needs to be conducted. Researchers need to investigate the impact of conceptual knowledge, instruction, and creativity on students asking and defining problems.

The 1988 problem-solving research in science education presents some interesting and fruitful trends. As the research in problem-solving continues to evolve, researchers need to focus more closely on the impact of conceptual and strategic knowledge, instructional treatments to improve problem-solving, complex problem-solving situations and the use of new technologies to promote problem-solving. Researchers also need to investigate the problem-solving performance of learners at a variety of different school levels. "How can the problem-solving behaviors of middle school students be enhanced?", is an important question which needs careful examination. This commentary was written to encourage an increase in these research trends.

8.0 Achievement

The studies included in this chapter of the review are concerned with six major areas: the status of achievement (5 studies), correlates of achievement (13 studies), interventions and achievement (12 studies), perceptions of achievement (1 study), gender differences (4 studies), and process skill attainment (8 studies). Studies in the status section focus on the science achievement of select groups. In the correlates section, studies look at the relations of learner characteristics and other factors to science achievement. Instructional, pre-instructional, and parental treatments are the foci of studies included in the intervention section. In the perceptions section, attributes perceived to be related to students' success in science are examined. Studies in the gender differences section highlight the relations between gender and science achievement. In the process skills section, studies examine factors related to process skills attainment, process skill hierarchies, and difficulties associated with written process skill tests.

8.1 Status of Achievement

8.11 What is the status of achievement in New York City?

Abbott and Lisa-Johnson reported on a New York City science survey administered to fifth and eighth graders in May, 1987. The fourth survey administered in as many years, it assessed overall science achievement by including questions from the biological, physical, and earth/space sciences. Special questions on geology, weather, and astronomy were added for eighth graders. More than 100,000 students were surveyed. The results showed that science achievement in fifth grade improved over that reported for 1986, but performance in chemistry was low. The implementation of a new curriculum made it difficult to compare the eighth grade results with those from previous years. Overall, the 1987 survey was found to be difficult for students, with an average of only 48 percent of the 60 questions answered correctly. Abbott and Lisa-Johnson proposed the use of data to plan instructional and staff development programs.

8.12 How knowledgeable are students about the ocean and the Great Lakes?

Fortner and Mayer assessed ocean and Great Lakes awareness among fifth and ninth graders as part of the Ohio Sea Grant Awareness Education Program. Data were collected in 1983 and compared with 1979 data to determine the following: how students' knowledge and attitudes about the ocean and Great Lakes changed over the four years; what students know about Great Lakes topics presented through the Oceanic Education Activities for Great Lakes Schools (OEAGLS); and, what sources students used to acquire information about the ocean and Great Lakes. Over 3000 fifth and ninth graders attending schools varying in proximity to Lake Erie served as subjects. Students who were fifth graders in 1979 and ninth graders in the year 1983 enjoyed a 10 percent increase in knowledge, but their attitudes, while remaining slightly positive, changed little. Moreover, ninth graders' knowledge scores in 1979 and 1983 were virtually identical, suggesting little progress in ocean and Great Lakes awareness. According to Fortner and Mayer, the lack of progress is related to the low number of teachers who use OEAGLS materials. However, students reported a greater availability of aquatic information in 1983 than in 1979.

8.13 How knowledgeable are students about health and physical fitness?

Merkle and Treagust studied eighth and ninth grade students' (n = 109) knowledge of personal health and physical fitness and its relation to locus of control. Following instruction, data were collected using a 20-item true-false test with an added opportunity for students to explain their understandings of health and fitness. The second variable was measured with two subscales from the Multidimensional Health Locus of Control Scale. Students scored well on the true-false items, but their explanations revealed numerous misconceptions about health and fitness. Locus of control scores showed that students assume greater control for fitness. Correlation data suggest that students scoring low on knowledge believe that their personal health and physical fitness is more a factor of chance than do students scoring high on knowledge. The study also produced a two-tier diagnostic instrument for identifying students' misconceptions about health and fitness.

8.14 How well informed are students about acidic deposition?

Brody, Chapman, and Marion interviewed 175 fourth, eighth, and eleventh grade students in Maine to ascertain their understanding of acidic deposition. Student knowledge of the 12 principles was rated at four levels of understanding: complete, high, low, or no understanding. Grade level differences were realized for all principles except one: acid deposition affects natural resource utilization in recreation and agriculture. Important concepts were omitted for each principle. Among the missing concepts were the following: sulfuric and nitric oxides contribute to the production of acidic precipitation; chemical pollutants and water combine in the atmosphere as a result of reactions triggered by the sun; and, acid deposition affects natural resource utilization. According to Brody, Chapman and Marion, students grasp only a small portion of what is essential for adequate understanding of acidic deposition.

8.15 How learned are college students about models and model building?

Assuming that science is the process of constructing predictive models, **Gilbert** questioned the usefulness of student conceptions of models and model building as an organizer for understanding the nature of science. Six hundred eighty-seven undergraduate general biology students responded to two sets of statements modeled after items appearing on the Views of Science-Technology-Society instrument. Here students harbor many misconceptions about the processes of science, models and model building. A number of students viewed models as simply replicas, and their poor grasp of the nature of science impeded their responses about the interaction of theories and laws of biology, chemistry, and physics. Gilbert concluded that the prototypical nature of models could advance students' conception of scientific knowledge, but only if instruction is directed at student understanding of models and model building.

8.2 Correlates of Achievement

8.21 Which learner characteristics relate to achievement?

Rochford examined the relationship between achievement and spatial ability of South African university students studying anatomy, astronomy, and engineering. Measures testing geometric spatial ability, anatomical spatial achievement, non-spatial anatomical achievement, and astronomical spatial proficiency were administered to 621 students. Student performance on examinations in anatomy, descriptive astronomy, and engineering drawing was significantly impacted by spatial ability. In addition, tests of anatomical and astronomical spatial proficiency were better predictors of academic success than were geometrically-based tests of spatial ability.

Impelled by the undocumented relationship between selection procedures of the gifted and their performance, **Consuegra** sought to determine if achievement of seventh grade gifted students could be predicted from several variables, both tried and untried. The predictor variables consisted of standardized achievement and ability test scores, teacher ratings, and previous science performance as well as science interest and thinking skills. Achievement, the criterion variable, was operationalized as the sum of seventh grade gifted science report card grades over four reporting periods. A regression equation designed to test the relationship accounted for 36 percent of the variance in student performance. The three predictor variables included in the equation were: the sum of science grades over four grading periods, work-sample raw scores on the Orleans-Hanna Algebra Prognosis Test, and scale scores on the California Achievement Tests-Reading Vocabulary Subtest.

Jeong analyzed the records of 546 Korean students seeking relationships between science achievement and select variables. In addition to intelligence and aptitude, the predictor variables included scores for Korean language, English, mathematics, general science, and all ninth grade subjects. Achievement in tenth grade biology and chemistry and eleventh grade physics and earth science served as the criterion variables. Jeong's data analyses revealed the following: the ninth grade total score was the single best predictor for all criterion variables; the predictor variables correlated higher with the tenth grade criterion variables than with the eleventh grade criterion variables; and, the six predictor variables explained a significant portion of the variance of all four criterion variables.

Tracy explored the relationships among the toy-playing behavior, sex-role orientation, spatial ability, and science achievement of 283 fifth graders. Data were collected using the Iowa Test of Basic Skills-Science and the newly developed Tracy Toy and Play Inventory, a modified version of the Bem Sex-Role Inventory which is a standardized spatial ability test. The findings indicated that science achievement is not affected by four different sex-role orientations or gender. However, spatial ability was found to be related to gender and science achievement, with boys having significantly better spatial skills than girls and students with high spatial ability having significantly higher science achievement scores. Moreover, femininely-oriented boys who scored low in the proportional-arrangement and gross body-movement toy categories earned significantly higher achievement scores than did girls with the same sex-role and toy-playing behavior.

Tamir (b) investigated the relationship of the cognitive preferences of Israeli students to their achievement in science and four background variables: gender, sociocultural status, school-related variables, and career choice. Cognitive preferences in this study were the choices granted to students as they attended intellectually to scientific information. There were four choices: acceptance of information for its own sake, designated as recall (R); acceptance of information because it explains a fundamental scientific principle, designated as principles (P); critical questioning of information in regard to completeness or validity, designated as questioning (Q); and, acceptance of information in view of applicability, designated as applicability (A). Principles, questioning, and applicability are classified as high preference, and recall is categorized as low preference. Three instruments were administered to 501 twelfth grade students: the Student Background Questionnaire, the achievement tests designed by the staff of the International Association for the Evaluation of Educational Achievement, and Health's Combined Cognitive Preference Inventory. Tamir reported that higher sociocultural status, higher achievement, liking science, commitment to science homework, and an intent to study science in college are associated with higher preferences for principles (P) and critical questioning (Q), whereas a lower preference was registered for recall (R). Science majors were prone to exhibit a higher level of intellectual curiosity than were non-majors. The cognitive preferences of males and females were similar.

McCammon, Golden, and Wuensch chose thinking skills and mathematical competence as predictors of performance in college physics. The subjects were 206 freshman and sophomore science majors. Measures testing thinking skills and mathematical competence were those well established in the literature. Performance was measured by course examination scores. Skills in algebra and critical thinking were the best overall predictors of performance in physics. Arithmetical skills, mathematics anxiety, and primary thinking skills correlated with performance, but they were redundant with algebra and critical thinking. When data for male and female subjects were disaggregated and correlated with performance, the predictor variables were successful in predicting course performance for females but not for males.

Mitchell and Lawson tested five predictors of achievement in Mendelian genetics: hypothetico-deductive reasoning (i.e., three Piagetian levels of intellectual development); degree of field-independence; mental capacity; fluid intelligence; and, prior knowledge of genetics. The subjects were 98 undergraduates who were taught a unit on Mendelian genetics as part of a biology course. Achievement was measured by five subtests dealing with genetics. Four predictor variables were measured by well established instruments, and prior knowledge was tested by 10 multiple-choice questions and two genetics problems. Level of intellectual development best predicts achievement, and prior knowledge in genetics is the poorest predictor, concluded Mitchell and Lawson.

Zeitoun investigated the relationship between students' achievement of abstract concepts in molecular genetics and prior knowledge of molecular genetics, reasoning ability, and gender. Data were collected by administering the Test of Logical Thinking and two measures of genetics knowledge to 160 secondary students who attended a select school in Egypt. Zeitoun concluded that both prior knowledge and formal reasoning have considerable effect on students' acquisition of abstract concepts in molecular genetics. However, prior knowledge is the single most important influence.

Osuagwu investigated the relationship between students' antecedent knowledge, cognitive development, and achievement in genetics. Subjects were high school graduates randomly selected from four government colleges in Nigeria. The Longeot Test assessed cognitive development, and antecedent knowledge was measured with a 25-item multiple-choice test and items from a figurative-based analytical task. Students' achievement was assessed by a 30-item multiple-choice test, and a subsample of students were interviewed to provide additional insight on their knowledge of genetics. Genetics achievement was significantly related to students' cognitive development, their antecedent knowledge, and their ability to catalog the antecedent knowledge. According to Osuagwu, the findings suggest that students' achievement in genetics may be impaired by cognitive limitations and deficiencies in antecedent knowledge in meiosis, fertilization, and sexual reproduction.

8.22 What factors combined with learner characteristics relate to achievement?

Using data collected as part of the Second International Education Assessment Science Study, **Chandavarkar** sought to identify classroom practices and teacher and student attributes associated with improved achievement in high school physics. Data from 2,719 U.S. students were used to design a structural model of classroom learning in physics. The findings are reported here in part: males outperformed females in physics; tenth and eleventh grade students performed as well on physics tests as twelfth grade students; achievement of U.S. physics students was lower than comparable English and Japanese students; learning opportunities and graded homework are associated with physics achievement; and, significant predictors of achievement were prior science learnings, community and home characteristics, peer attitudes, science attitudes, gender, and curriculum factors teachers consider important. Chandavarkar called for some physics to be studied each year, more homework to be assigned that will be scored, and more individualized physics programs to be offered.

Menis explored the relationship between teaching behaviors and student performance on the proportion concept in biology, chemistry, and physics classes in upper secondary-level schools in Canada. Central to the study was the behavior of teachers as reported by students who responded to a 24-item instrument assessing teachers' instructional behaviors. Also measured was student understanding of the proportion concept using 14 items relating to topics in biology, chemistry, and physics. Student performance and student estimates of the frequency of teaching behaviors displayed in the science classroom were analyzed. High achievers were prone to assess highly teachers who use their own ideas in planning, use demonstrations to explain science, make science interesting, encourage students to copy the teacher's notes, emphasize relevancy of science to life, discuss science careers, and help and encourage students to arrive at their own solutions to laboratory or field problems. Achievement in the proportion concept, concluded Menis, seems to be related to teacher behaviors.

Teacher performance using the Florida Performance Measurement System (FPMS) was assessed in **J. T. Crosby's** study. Student performance was assessed by tests of science content and science processes. Investigated were the relationships between FBMS teacher scores on the regular science classroom and the science laboratory, student achievement, and student task engagement. The FBMS scores were significantly higher in the regular classroom than the laboratory, reported Crosby. There was a positive and significant correlation between scores in the two classroom settings. Also, positively and significantly related were combined teacher scores and combined student task-engagement scores, as were combined teacher scores and combined student achievement scores. Student task-engagement and achievement were unrelated.

Okpala and Onocha gathered information from 4,344 secondary physics students in Nigeria to identify the topics considered difficult by the students, and to determine if a relationship exists between the number of mathematics courses taken and students' perceived difficulty in learning physics. Students reported more difficulty in mechanics than in all other physics topics. Moreover, a significant, positive relationship was discerned between advanced study of mathematics and perceived ease of learning physics.

8.3 Interventions and Achievement

8.31 What instructional interventions affect achievement?

Pauline (also see **Pauline and Bell**) examined the respective and combined effects of feedback and review on students' achievement, retention, and level of cognitive development. Fifty-five ninth graders experienced an interactive slide/sound computer lesson on the history of the earth, and they responded to 26 self-test questions. Five treatments were tested that varied feedback and review. A 28-item achievement test was administered to all subjects immediately after the treatment and one week later. Feedback increased overall achievement and retention. Feedback also increased performance on test items that represented higher cognitive development. In comparison, the reviews produced significant improvement only on the higher cognitive development test items. The improvement realized for combined content feedback and review was not significantly different from that realized for the two strategies separately.

Browning tested the effect of two levels of genetics instruction and two levels of instructional sequence on student achievement in genetics. Instruction was delivered via a microcomputer tutorial to 83 students, 41 of whom were volunteers. The two levels of genetics instruction consisted of the following types of integration: genetics context to explain the products of gametogenesis, and meiosis presented separately from genetics inheritance. The presentation of autosomal inheritance patterns followed by sex-linkage and the reverse sequence, suggested by Tolman, comprised the two levels of the instructional sequence. The achievement measure, developed by Browning, included questions on definitions in genetics, the relationships between genetics terms, and familiar and novel genetics problems. Using only the data generated by the non-volunteer subjects, the results support the use of the integrated instructional approach but fail to provide sufficient evidence to advocate the use of the instructional sequence proposed by Tolman.

The effect of supplementary instructional materials and increased teacher-directed instructional time on science achievement was tested by **Frieske**. The sample consisted of 130 fifth graders from a single Oregon school district. The supplementary instructional materials dealt with green plants, and they took two forms: computer assisted instruction and reading materials with worksheets. Forms P and Q of the science portion of the Survey of Basic Skills-Level 34 (SRA) served as pre- and posttest measures, respectively. Supplementary instruction plus increased teacher time did not significantly improve student achievement.

Abayomi probed the effect of two instructional strategies, cognitive style, gender, and their interactions on the science achievement of 156 eighth graders from three different Atlanta-area schools. Three teachers taught the same instructional unit using either a concept-mapping strategy or an outlining study guide. Each student's cognitive style was classified as either field-dependent or field-independent based on results of the Group Embedded Figures Test. Results of the study revealed no significant difference between achievement scores due to instructional strategy, cognitive style grouping, gender, or the interactions of these variables. The one-on-one interviews revealed favorable student feelings toward the concept-mapping strategy.

Hall and McCurdy compared the effects of a Biological Sciences Curriculum Study (BSCS) laboratory and a traditional laboratory on student achievement, reasoning ability, and attitude toward science. The sample consisted of 119 biology students at two private, midwestern liberal arts colleges. Students in the BSCS group experienced process skill learning and concept development through extensive questioning, while other students experienced highly structured, teacher-oriented laboratory activities. The BSCS group scored significantly higher than the comparison group on achievement, but not on measures of reasoning ability and attitude. Moreover, an increase in the number of formal thinkers was found for both groups. According to Hall and McCurdy, the results support the BSCS-style laboratory approach in college biology courses.

Scallan tested the effect of guided practice on student achievement in fifth and sixth grade science and social studies classes. The sample included all fifth and sixth grade students in a small north Texas school district. In the experimental treatment teachers made extensive use of guided practice. The same content taught without guided practice constituted the control. Guided practice resulted in significant gains in fifth grade, but not in sixth grade classes. Scallan suggested that teacher effect may have influenced the findings.

One hundred seven students enrolled in a biology course served as subjects in an experiment conducted by **Lord.** Subjects were randomly-assigned to either a control, placebo, or experimental group. During the 15 weeks of the treatment, the control group followed an instructional scheme that included two lectures, one lab, and one seminar each week. For the placebo group a 20 to 30 minute presentation on the historical significance of each lab was added. For the experimental group a 20 to 30 minute treatment was added each week to enhance student visuo-spatial potential. At the end of the treatment, students responded to a written examination and a lab test. Significant differences were found between the experimental group and the other two groups on the lab practical, but not on the final exam.

8.32 What are the effects of parental involvement on achievement?

Nelson questioned if parental knowledge of classroom objectives would influence student achievement in physical science. Students from two physical science classes were randomly divided into experimental and control groups. Course objectives for the semester were sent to parents of students ($n = 17$) in the experimental group, while parents of students ($n = 16$) in the control group were not informed. Parental knowledge of classroom objectives had no significant effect on student achievement.

Parent-child and student-student pairs were compared in an investigation reported by **Heller, Padilla, Hertel, and Olstad**. Two studies were conducted to determine whether achievement and attitudes differ when students take a technology and computer course with parents or with peers. The first study, conducted in Minnesota, consisted of teaching a communications technology course three times, first to twelve families in the parent-child treatment, next to twenty-four children in the student-student treatment, then to another twelve families in the parent-child treatment. The second study conducted at sites in Athens, Georgia and Seattle, Washington consisted of fifty children in the child-child treatment and sixteen families in the parent-child treatment. Instruments measured achievement, perceived skill gains, and attitudes toward the course, the subject matter, and partners. Parents had no more influence than peers on achievement and perceived skills. Subjects in student-student pairs expressed a more negative partner attitude but a more positive course attitude than parent-child pairs. Results, according to the authors, were attenuated by the fact that students participating in the studies were high achievers, interested in and motivated to learn the subject matter. Significant differences were noted for computer literacy favoring parent-child diads in the second study.

8.33 Do pre-instructional experiences affect chemistry achievement in college?

Boyd, Carstana, Hunt, Hunt, Magoon, McDevitt, McLaran, and Spokane invited 484 registrants of a university chemistry course to listen to audiotutorial tapes on the basic concepts and calculations of chemistry as a precourse refresher. Eighty-one of the invited registrants chose to listen to the tapes. Seventy-six commuters served as a control group. Sixty-nine percent of the students in the experimental group and 57% of the commuters earned a final grade of C or better. The user-group was significantly better in terms of academic persistence and semester grade point average weeks after the intervention. The authors considered the treatment as an effective means of helping students succeed in chemistry, but they acknowledged that it is not possible to separate the effects of self-selection from treatment.

Yager, Snider, and Krajcik compared the effects of a high school chemistry course on student success in college chemistry. The study sample was 53 high-ability senior high school students, only half of whom had completed a high school chemistry course. All students enrolled in a general college chemistry course met daily during an 8-week summer session held at the University of Iowa. The course was taught by a regular chemistry instructor who used regular semester instructional materials and tests. No difference between the groups was discerned on attitude toward chemistry, performance on the final course examination, a standardized chemistry achievement examination, and course grade. However, more time was required of tutors for the students who had not completed high school chemistry. According to Yager, Snider, and Krajcik, the results contradict the assumption that traditional high school chemistry is important as preparation for the study of general college chemistry.

8.34 Does the matching of students and teachers on cognitive style affect achievement?

Reports in the literature suggest that students learn best when taught by faculty who match their cognitive style. Prompted by this premise, **Shmaefsky** compared the success of college science students (n = 213) whose cognitive style matched their instructor with students whose cognitive style did not match. Students in the former group earned a significantly higher final grade than did their counterparts. Also, instructors whose cognitive style matched their students enjoyed more favorable course evaluations. Post-hoc analysis revealed that student gender and course grade were related to student course evaluation.

8.4 Perceptions of Achievement

8.41 What knowledge, skills, and personal attributes are perceived to be important for high school students planning to study biology in college?

This question was investigated by **Susilo** by surveying second year university biology students, high school biology teachers, college biology professors, and science educators in the U.S. and Indonesia. The American respondents rated knowledge of biological definitions as most important, especially biology teachers. The Indonesian respondents, except for the high school biology teachers, rated highly knowledge that connects perceptions. The application of knowledge was rated as most important by the Indonesian biology teachers. All respondents from both countries rated general skills (e.g., ability to read a graph and interpret data tables) well above biological, knowledge based skills (e.g., using a Punnett square). Creativity and ingenuity were perceived as notably valuable.

8.5 Gender Differences and Achievement

8.51 What is the relationship between gender and achievement?

Humrich reported on the results of the Second International Educational Assessment Science Study (SISS) in the U.S. Central to her report were gender differences in science achievement and process scores. Achievement data were collected from a total of 16,754 students in grades five, nine, ten, and twelve; manipulative process data were collected from 5,358 fifth and ninth graders. Differences in science achievement favored males at all grade levels and in every secondary subject area, i.e., first-year and advanced biology, chemistry, and physics. Testing the effect of gender on science achievement, female science teachers failed to increase the level of female achievement. Moreover, a female teacher seemed to have a negative effect on girls' achievement at the ninth grade level and in first-year physics and advanced chemistry. But, female teachers positively influenced achievement of both girls and boys in first-year biology. The manipulative process scores registered no significant differences between fifth grade boys and girls, but differences on select items favored boys at the ninth grade level. The results of the U.S. study, as do the preliminary reports filed by other nations involved in the SISS, suggest that gender differences in science achievement prevail 13 years after the First International Educational Assessment Science Study. Process-oriented learning tasks are recommended by Humrich as a means of achieving gender equity in science teaching.

The British public's knowledge of elementary physics was the subject of a survey conducted by **Lucas**. A representative sample of 1,033 people, ages 15 and over, were interviewed to determine the public's knowledge of basic concepts in physics. Participants were asked 24 questions consisting of true-false, multiple-choice, and free-response items. Lucas concluded that very little physics is remembered into adulthood and that women as a group are less successful than men, answering more physics questions incorrectly and more frequently using the "don't know" response option.

Esquivel and Brenes analyzed gender effects in science and mathematics achievement data from Costa Rican fourth, sixth, seventh, tenth, and eleventh graders. Data were collected as part of a project executed by the Research Institute for the Improvement of Costa Rican Education from 1982 to 1986. Data analyses revealed no significant differences in science and mathematics achievement for fourth grade boys and girls. However, males significantly out-scored females in science and mathematics achievement in grades six, seven, ten, and eleven. Throughout Costa Rica all students must enroll in the same science curriculum through grade eleven. Therefore, Esquivel and Brenes ruled out curriculum inequities as the factor responsible for achievement differences.

Al Methen and Wilkinson investigated the relationships between gender and achievement in chemistry, physics, biology, geology, and mathematics for societal subgroups in Kuwait. The sample for the study consisted of 1,745 Kuwaiti and 2,833 non-Kuwaiti students who responded to the Kuwaiti Secondary School Certification Examination during the 1982-83 academic year. Forty-two percent of the total sample were females who studied all the science subjects including mathematics, and 21 percent of the total sample attended rural schools. Girls scored significantly higher than the boys in all science subjects; however, in mathematics the reverse was true. When the results were examined on the basis of nationality, non-Kuwaiti students scored significantly higher than Kuwaiti students in biology, chemistry, physics, geology, and mathematics. Moreover, boys who attended rural schools scored significantly higher in biology, chemistry, and physics, but not in geology and mathematics than those who attended urban schools. In comparison, girls who attended urban schools achieved significantly higher scores than girls who attended rural schools in biology, chemistry, physics, geology, and mathematics. Other comparisons among subgroups of the sample (e.g., Kuwaiti girls vs. Kuwaiti boys and non-Kuwaiti students in rural areas vs. non-Kuwaiti students in urban areas) revealed findings similar to those reported above. Al Methen and Wilkinson remind the reader that the findings of this study that contradict the findings of similar studies in Western Countries are due more to Kuwaiti sociological factors than biological factors.

8.6 Process Skill Attainment

8.61 What factors relate to student proficiency in the use of process skills?

The contributions of cognitive development and field-dependence-independence on high school students' mastery of line graphic skills were investigated by **Hinduan**. The sample consisted of 108 students enrolled in ninth and tenth grade science courses in the same school district. Students were given the Test of Graphing in Science, a modified version of the Test of Logical Thinking, and the Group Embedded Figures Test. Although no significant differences were found between formal-operational and transitional students on the measure of graphic skills, formal and transitional students performed significantly better than concrete-operational students on the same measure. Significant differences in performance were also found for items classified as to level of cognitive demand, with a significantly higher percentage of concrete-operational items correctly answered than items classified as requiring formal-operational or transitional reasoning. In addition, field-dependence-independence was correlated weakly but significantly with both graphing ability and cognitive development.

The performance of elementary education majors with varied cognitive-style preferences on integrated science process skills was investigated by **Nakayama**. One hundred seven subjects completed two evaluative instruments, the Learning-Style Inventory (LSI) and the Test of Integrated Process Skills II (TIPS II). The LSI measures cognitive style as two sets of dualities (i.e, perception types and processing types), whose combinations result in four learning styles. Significant differences in performance on integrated science process skills were found between students with different perception preferences. Overall, abstract conceptualizers out-performed students whose preference was concrete experience. However, the reverse was true for operationally defining, one of the process skills. For the processing dimension, differences favored students who preferred active experimentation over reflective observation, but only for the skill of operationally defining. Nakayama concluded that performance of integrated science process skills is influenced by cognitive-style preferences.

Lavoie and Good set out to understand and describe the mechanisms of thought associated with predicting, a science process. To this end, they investigated the relationship of prediction-related behaviors to initial knowledge, stage of Piagetian development, prediction success, and the learning cycle. Interviews prior to the study identified 63 cognitive process behaviors associated with program exploration and prediction. The performance of seven formal-operational and seven concrete-operational biology students was videotaped as they responded to a three-phase, learning-cycle exercise on water pollution. Using a computer simulation, students predicted the effects of five independent variables (temperature, waste type, dumping rate, treatment, and type of body of water) on two dependent variables (oxygen and waste concentration) over time. The videotaped behaviors of the 14 subjects were analyzed using verbal protocol and comparative systematic analyses. Behaviors were tallied for each subject. Comparisons were made between successful and unsuccessful predictors, concrete and formal subjects, high-initial and low-initial knowledge subjects, and prediction at stage-one and stage-three of the learning cycle. Generally speaking, successful predictors were formal-operational, and their initial knowledge of the subject matter was high. By contrast, unsuccessful predictors were concrete-operational, and they exhibited low initial knowledge. High initial knowledge was more predictive of success than stages of Piagetian development, Lavoie and Good concluded.

Radford compared a lecture-class discussion approach versus a laboratory-activity approach on students' acquisition of science process skills. A tenth grade advanced biology class was assigned to each treatment. At the completion of the two-week study, data were collected using the Middle Grades Integrated Process Skills Test (MIPT). The results indicated that integrated science process skills can be successfully taught to students using the lecture-discussion approach with no loss of achievement. Radford recommended that the lecture-discussion approach should not be used to supplant laboratory instruction.

Ahmed investigated the level at which science process skills are integrated into laboratory work of intermediate biology courses in Pakistani colleges. Data were collected by examining laboratory guides, interviewing lecturers, observing biology classes, and analyzing student responses to a criterion-referenced test of science process skills. The results disclosed the following: popular laboratory guides do not emphasize process skills;

lecturers give priority to content over process skills, with the exception of observation skills; and, few students achieved the desired competence in the process skills as measured by the criterion-referenced test. Students attending colleges using the state-prescribed laboratory guide were prone to achieve the desired level of competence in process skills. According to Ahmed, the final practical examination drives lecturers to de-emphasize process skill learning.

8.62 Do hierarchical relationships exist among process skills?

Flower sought hierarchical relationships among science process skills. And, if the hierarchies do exist, how do they differ when learning-disabled students are compared with non-disabled students? Fifty-five learning-disabled and 543 non-disabled students from grades four through eight completed a 36-item assessment of six integrated science process skills. The results were analyzed with the Test of Inclusion, a three-by-three matrix design that determines if one skill is a prerequisite of another. The results manifested no hierarchical relationships among the six process skills, and a second attempt to find hierarchies through the construction of scalograms was also unsuccessful.

Yap and Yeany sought hierarchical relationships among six Piagetian cognitive modes and five integrated science process skills for three cognitive reasoning levels, and to determine whether positive vertical transfer can be substantial. The cognitive modes tested were controlling variables and conservation, proportional, probability, correlational, and combinatorial reasoning. The process skills tested were identifying variables, identifying hypotheses, operationally defining variables, designing experiments, and graphing and interpreting data. Cognitive modes and process skills were tested by instruments well established in the literature. Tested were 741 students in grades 7-12, where 113 were categorized at the formal operational level of cognitive reasoning, 162 at the transitional level, and 466 at the concrete operational level. Bart and Airasian's ordering theoretic procedure and Dayton and Macready's probabilistic latent structure method were used to identify hierarchical relationships and the best-fit hierarchy for the set of skills in each Piagetian cognitive reasoning level. Then, sets of subordinate and related superordinate skills were validated by the vertical transfer method. Results revealed the lack of a hierarchy of skills among formal-operational students, limited hierarchical relationships and no transfer of skills among transitional students, and four subordinate to superordinate relationships of the modes and skills among concrete-operational students. Yap and Yeany concluded that hierarchical links exist between Piagetian cognitive modes and integrated science process skills.

8.63 Does question format affect performance on a written test of process skills?

Shaw, McKenzie, and Kuehn studied the performance of 54 high school students on four types of multiple-choice items commonly used to assess ability to identify manipulated and responding variables. Items differed only in the stimulus material given to students which took one of four forms: a question focusing on the relationship between two variables, a hypothesis, an experiment description, or a description of the results of an experiment. The "results" format was the easiest and the "question" format was the most difficult. The correlation between the manipulated variable subtest and the responding variable subtest was low and negative; and, the "description" type had a higher correlation with performance on a standard Piagetian interview task of variable identification than any other item type. Shaw, McKenzie, and Kuehn concluded that ability to identify the manipulated variable in an experiment may not be assured by one's ability to identify the responding variable and vice versa, and that assessment of both should include written and interview formats.

8.7 Invited Commentary — John Staver

Several years ago, Ausubel (1968) stated that the most important factor in learning something new is what the learner already knows. Different interpretations of the meaning of the clause "what the learner already knows" in Ausubel's statement reflect an on-going competition between two theoretical positions. One position, advocated by Joseph Novak at Cornell University, maintains that learners integrate new knowledge with existing conceptual frameworks relevant to the new knowledge. Thus, what the learner already knows is interpreted to be a well structured network of domain specific declarative knowledge. New learning in a specific domain is integrated into the existing conceptual framework of that domain. A competing theoretical position, advanced by Anton Lawson at Arizona State University, asserts that developing reasoning ability, or general procedural knowledge, is at least as important as domain specific declarative knowledge in learning something new. Thus, "what the learner already knows" is interpreted to mean the ability to use general, procedural as well as domain-specific, declarative knowledge in learning new information.

As I reviewed the contributions to the literature on science achievement during the 1988 calendar year, a small group of studies attracted my attention more than the others. This does not imply that other studies are not worthy of comment; it means only that this group of studies contributes directly to the above-mentioned competition between theories of knowledge acquisition in science; and, therefore, I wish to focus my reaction on this issue.

For example, Mitchell and Lawson report that the level of intellectual development, using a Piagetian model, is the best predictor of achievement in Mendelian genetics, while prior knowledge in genetics is the poorest predictor. Zeitoun concludes that prior knowledge and formal reasoning exert considerable effects on the acquisition of abstract concepts in molecular genetics; however, prior knowledge is the most important influence. Osuagwu states that achievement in genetics is significantly related to students' cognitive development, antecedent knowledge, and ability to catalog antecedent knowledge.

The Mitchell and Lawson study on Mendelian genetics provoked a response from two researchers whose theoretical position is aligned with that of Novak. Bob Hafner and Jim Stewart (1989) criticized Mitchell and Lawson's conclusions as unfounded, as based on the data collected and analyzed. Hafner and Stewart argued that Mitchell and Lawson did not:

> (1) discuss the theoretical relevance of the predictor variables to genetics problem solving; (2) use adequate techniques to assess knowledge of genetics and problem-solving performance; (3) provide data to support conclusions about sources of problem-solving difficulties; or, (4) provide evidence that causal claims about the sources of difficulty experienced by individual students can be drawn from group data (p.551).

Lawson (1989) replied to Hafner and Stewart's comments and criticisms, arguing that, although the individual interview method advocated by Hafner and Stewart is reasonable, so also are group methods. In addition, references establishing the theoretical relevance of predictor variables were cited. Lawson addressed the issue of competing theoretical positions directly, saying, "The Hafner/Stewart comments simply represent one more volley in a long line of Ausubel versus Piaget, Novak versus Lawson, specific declarative knowledge versus general procedural knowledge disputes. With the Hafner/Stewart comments, the Ausubel/Novak specific declarative knowledge camp has once more advocated its disinterest in scientific reasoning" (1989, p.555).

This snapshot represents what research is all about, researchers battling tooth and nail in behalf of a theoretical position and against competing theoretical positions. And that is my point. These studies, more than the others, provide a brief picture of science in action at a specific moment in time, a picture of competing alternative hypotheses or theoretical positions being presented, tested, and discussed in the social arena of humans doing science. I am sure that Kuhn and Lakatos would smile and nod their approval.

Moreover, another chapter in the continuing competition will soon surface. In an unpublished paper, Lawson and several co-workers (1989) tested the hypothesis that the acquisition of domain-specific conceptual knowledge requires the use of general procedural knowledge. Specifically, Lawson and his associates hypothesized that hypothetico-deductive reasoning is necessary for the acquisition of novel domain-specific concepts. They tested the hypothesis by administering a series of four descriptive concept acquisition tasks to 314 high school biology and chemistry students whose ability to use hypothetico-deductive reasoning was previously determined. The four descriptive concept acquisition tasks required students to determine membership in four hypothetical groups called Gligs, Skints, Mellinarks, and Quarks. The tasks were taken from the activity entitled Creature Cards, which is part of the Elementary Science Study (1974). Analysis of students' performance data and think-aloud interviews on the tasks supports the investigators' hypothesis. In their discussion of the results, Lawson and his co-workers state that this study did not test the alternative hypothesis that domain-specific knowledge is required to acquire novel domain-specific concepts. Thus, researchers should not view these results as contradictory to that hypothesis. But the results are contradictory to Novak's (1977) position that children utilize frameworks of specific concepts, not general cognitive operations, to make sense of their experiences.

To establish further his point, Lawson communicated personally with Ausubel to obtain his interpretation of "what the learner already knows." Ausubel stated that procedural as well as declarative knowledge must be included in what the learner already knows. Ausubel went on to say that procedural knowledge plays a more fundamental role in learning due to its general nature and relevance to all learning, whereas domain-specific, declarative knowledge is important only when new learning is concerned with that domain, and only when relevancy is established by means of an advance organizer or other means of conceptual connection (Lawson et al., 1989).

And so the competition continues. To provide further impetus, I conclude my reaction with the following question, addressed to all advocates of both theoretical positions: What empirical evidence would be required to be able to reject each theoretical position?

References

Ausubel, D.P. (1968). Educational psychology: A cognitive view. New York: Holt, Rinehart, and Winston.

Elementary Science Study. (1974). Attribute games and problems: Teacher's guide. New York: Webster Division, McGraw Hill.

Hafner, B., & Stewart, J. (1989). A comment on predicting genetics achievement in nonmajors college biology. Journal of Research in Science Teaching, 26(6), 551-553.

Lawson, A.E., McElrath, C.B., Burton, M.S., James, B.D., Doyle, R.P., Woodward, S.L., Kellerman, L., & Snyder, J.D. (1989). Hypothetico-deductive reasoning and concept acquisition: A test of the constructivist hypothesis.

Lawson, A.E. (1989). A reply to Hafner and Stewart's comments on "predicting genetics achievement in nonmajors college biology". Journal of Research in Science Teaching, 26(6), 555-556.

Novak, J.D. (1977). An alternative to Piagetian psychology for science and mathematics education. Science Education, 61(4), 453-477.

9.0 Attitude

The attention given attitude, interest and other affective variables suggest that their influence on science-related behaviors is now recognized. With this in mind, the research was organized into five categories: affective constructs and their relations (3 studies), determinants of science-related behaviors (5 studies), beliefs and attitudes regarding school science (3 studies), factors related to attitudes, interests, and other affective variables (13 studies), and instrumentation in the affective domain (3 studies).

9.1 Affective Constructs and Their Relations

9.11 What is attitude and how is it related to other affective constructs?

Shrigley, Koballa, and Simpson reviewed and analyzed the sociopsychological literature from 1800 on for an operational definition of attitude; one that would differentiate it from belief, opinion, and value. They also weighed the consistency of important subcomponents as attitude evolved historically from a physical to a psychological concept. The four concepts, namely attitude, belief, opinion and value, exist at points along the cognitive-affective continuum. Evaluation, or feeling, is the heartbeat of attitude placing it fully at the affective pole of the continuum. Beliefs fit at many points along this continuum. Some are factual, and therefore cognitive, while other beliefs are non-factual and affective. Beliefs at the affective pole differ little from attitudes, which means that many affective belief statements serve as valid attitude items. Opinions, historically a competitor of attitude, list toward the cognition end of the continuum, but they are usually non-factual. They serve us better as verbal expressions than research variables. Values are evaluative but they are broader, more culturally-bound and more resistant to change than are attitudes. Values register as moral imperatives—right or wrong; attitudes register as preferences—likes or dislikes. Attitudes are learned. They provide us with a readiness to respond to real-life situations, at times encounters for which we have had no prior experience. Attitude and behavior are correlates, but lack a literal or logical consistency. Scientific attitudes differ from science attitudes. The former are philosophical and cognitive; the latter are evaluative.

Laforgia analyzed the affective literature and commented on the means for evaluating affective objectives. The literature review contrasted attitude toward science and scientific attitude. Attitude toward science is defined as a learned response evaluating our feelings within the environment related to science learning. Scientific attitude is more aligned with student behavior that models attributes commonly associated with scientists such as curiosity, skepticism, and the willingness to suspend judgement. In the second part of the study, Laforgia noted the paucity of valid instruments for assessing affective objectives in science and identified means available for evaluating these objectives. Five evaluation techniques useful in the affective domain were identified. The closed-item questionnaire was recommended. Fakability, self-deception, and criterion inadequacy were described as limitations to the closed-item questionnaire. Fraser's Test of Science Related Attitudes and Billeh and Zakhariades' Test of Scientific Attitudes were recommended as valid, closed-item questionnaires for appraising science-related and scientific outcomes in the classroom.

Koballa (a) drafted a model of the relationships among several constructs of the affective domain. The model, based on Fishbein and Ajzen's Theory of Reasoned Action, suggests that a person's beliefs about a science-related object are the source of feelings toward the object. The feelings can best be described as attitudes. In turn, the person's attitude, mediated by personal and cultural values, determines the person's behavioral intention with respect to the object or issue. Finally, the behavioral intention closely relates to behavior. Three reasons for studying the science-related attitudes of students and teachers are elucidated. First, attitudes are relatively stable, yet they can be changed and the changes can be enduring. Second, attitudes are learned, suggesting that instruction in the cognitive domain can be applied to attitude change, e.g., gaining attention and enhancing comprehension. Third, attitudes are related to behavior, with the relationship viewed as correlational rather than deterministic.

9.2 Determinants of Science-Related Behaviors

9.21 What factors are associated with science-related behaviors?

Sayers investigated the relationship of self-efficacy, interest, and ability of students to their selection of science and non-science college majors. Ninety -five males and 163 females rated their interest in each of 30 college majors related to mathematics and science. They also responded to measures of self-efficacy for mastering the entry requirements for each college major. Significant gender differences were expressed for self-efficacy, consideration, and interest and within each of the three categories of college majors: fine arts and humanities, social sciences, and natural sciences. Furthermore, students' choices of college majors were predicted by self-efficacy, ability, and interest. Sayers concluded that differences in mathematics ability and the fact that some majors have traditionally been associated with either males or females play an important role in student choice.

Koballa (b) questioned 257 eighth grade girls to identify the referents most able to persuade females to enroll in an elective physical science course in high school. Attributes associated with these referents also were identified. The four referents, each of whom was identified by more than 10 percent of the sample, are cited here in order of perceived credibility: father, female science teacher, mother, and male high school student. Slight variations in the order of perceived credibility were recorded for different ethnic groups. Prestige and trustworthiness, Koballa noted, are the attributes more often associated with the communicators identified as highly credible.

Kelly surveyed more than 1400 third-year boys and girls at ten coeducational high schools to identify factors that influenced their choice of optional school subjects. Data were collected using the Options Questionnaire and the Technical Craft and Science Questionnaire. The most common reasons given for choosing subjects were usefulness for getting a job, interest in the subject, and personal performance in the subject. Perceived support from teachers and parents was the best predictor of the choice of physics and technical craft subjects (e.g., technical drawing and carpentry). Not surprisingly, males perceived greater parental and teacher support to choose physics and technical crafts, and they enjoyed these subjects more than did females. Kelly observed that gender is not directly linked to the choice of physics but is linked indirectly through students' perceptions of enjoyment, successfulness, and usefulness of the subject.

9.22 What is the efficacy of the Theory of Reasoned Action for understanding and predicting science-related behavior?

Crawley investigated the cognitive foundations and social support for teachers' decisions to engage in a select classroom behavior, implementing investigative processes in a physical science course. Participants were enrolled in a course developed for physical science teachers as part of a Summer Institute in Science funded by the Texas Higher Education Coordinating Board. The Theory of Reasoned Action provided the theoretical rationale for identifying teachers' behavioral intentions, attitudes toward the behavior, subjective norms, and the respective determinants of their attitudes toward the behavior and subjective norms. Teachers' intentions to use investigative methods in their classroom, Crawley concluded, are related to attitude toward the behavior, not subjective norm.

Koballa (c) tested the adequacy of variables central to the Theory of Reasoned Action that could serve as predictors of girls' intentions to enroll in at least one elective physical science course in high school. Data were collected from 94 eighth grade girls using a semantic differential scale. The findings, Koballa observed, support several hypotheses derived from the theory. Girls' intentions are a function of both attitude toward the behavior and subjective norm. Attitude toward the behavior has more influence on girls' intention than does subjective norm. And, academic ability, science grades, and attitude toward science fail to predict girls' intentions to enroll in at least one elective physical science course in high school.

9.3 Beliefs and Attitudes Regarding School Science

9.31 What are the attitudes of gifted students?

Selecting 32 attitude items from the scale used in the 1983 International Science Study, **Johnson and Vitale** tested 229 sixth through tenth graders attending the 1986 South Dakota Governor's camp for gifted students.

Factor analysis of the data identified four factors that accounted for half of the variance in students' total scores: science as a personal and national priority; science as taught in schools; the challenge of science and school; and, the fulfillment of school. Students view science as a national priority; they enjoy science as it is taught in school; and, they consider it a challenge. However, the same students fail to perceive school, in general, as challenging. Correlational analyses conducted by Johnson and Vitale further revealed that gifted students who consider science of personal value are likely to be more active in science class and the laboratory.

9.32 What are teachers' beliefs regarding the importance of laboratory work?

Gayford surveyed the beliefs of biology teachers in England and Wales toward the emphasis placed on certain aims of science laboratory work. The sample consisted of 265 teachers who prepare students for a 3-hour practical examination and 182 teachers who assess their students' laboratory work. The development of observational and descriptive skills ranked first among the aims expressed by both groups of teachers. Helping students work cooperatively with others ranked lowest in both groups. Significant differences in ratings were disclosed for other aims including the following: making theoretical work more understandable and developing the ability to carry out standard laboratory procedures. Moreover, teachers who personally assess their students' work place greater emphasis on experimentation and problem-solving than do teachers who prepare students for the practical examination. When compared to the findings of a similar study conducted a decade earlier, Gayford noted that the results reveal little change in teacher beliefs.

9.33 What do teachers and students think about the use of video programs?

Watts and Bentley interviewed a sample of teachers and 14, 15, and 16-year-old students from 13 schools in Great Britain. They assessed the opinions of teachers and students about the use of science video programs in science class, and how they would change the format of the programs, if given the opportunity. Watts and Bentley concluded that the best programs have a clear structure, present topics that are easily understood, serve as entertainment, and avoid gender and ethnic stereotyping.

9.4 Factors Relating to Attitudes, Interests, and Other Affective Variables

9.41 What school and cultural factors are related to attitude, interest, and other affective variables?

Empirical tests were conducted by **Krynowsky** (a) to verify relationships between student attitude toward tenth grade science and the learning environment. Three variables were identified accounting for 28.9 percent of the variance: satisfaction with their work in the class, interest in the class, and difficulty associated with science class. Other variables brought to light through student interviews included: clarity and organization of teacher explanations and perceived usefulness of science knowledge. The positive relationships found in the study prompted the development of a lesson that accommodates the theoretical tenets of attitude change put forth in the Theory of Reasoned Action. According to Krynowsky, a manipulation of select environmental variables should improve students' attitudes toward science.

The influence of grade level, gender, and intellectual ability on student attitudes toward science and scientific knowledge was tested by **Barrington and Hendricks**. One hundred forty-three third, seventh, and eleventh graders from two Wisconsin school districts served as subjects. Students with IQ scores greater than 130 on the Otis Test of Mental Ability were classified as gifted, and students scores between 95 and 105 were classified as average. A scale developed by Yager from items included on the National Assessment of Educational Progress' third assessment of science measured attitudes. Significant group differences were found in science knowledge, in composite attitude scores, and on two attitude scales where becoming a scientist and usefulness of science information were the objects. In all cases differences favored the gifted students. Moreover, a grade level effect was revealed on attitudes toward science class and science teachers, with third grade scores most positive and seventh grade scores most negative. A significant interaction was also found between grade level, student ability, and attitude toward science classes in grades seven through eleven. Here attitudes of the gifted were more positive than those of regular students. There was no gender effect noted by Barrington and Hendricks in any of the comparisons.

Wright tested the influence of grading and grade-related factors on attitude toward science and motivation to achieve in science. Data were collected from 130 secondary science students, and the scales used for data collection were published tests of attitude toward science and achievement motivation. Six researcher-developed subscales measured grade awareness, grade fairness, cooperation, grade reference system, grade range, and previous course grade. Grading factors accounted for 39 percent of the variance in attitude toward science and 23 percent of the variance in achievement motivation. All but two percent of the total variance in attitude scores was accounted for when grade range, grading awareness, and previous report card grade were combined. Previous grade, according to Wright, also accounted for most of the variance in achievement motivation, with grade range and grading awareness accounting for little variance.

In response to a drop in student scores on subscales of the School Attitude Measure following a year-long course designed to enhance scientific literacy, **Baker and Piburn** sought factors responsible for the decline. Data were collected from 83 ninth graders using a Likert scale and open-ended questions. The demands of the course, which stressed development of problem-solving and thinking skills, were related to the negative attitudes. Baker and Piburn made the following conclusions: student motivation declined because the course was viewed as irrelevant; performance-based self-concept declined due to students' perceived inability to be successful in science; feelings of personal control declined when students failed to associate success with effort; and, instructional mastery sagged because memorization was not stressed, given the nature of the course.

The cross-cultural nature of science-related attitudes was investigated by **Haukoos and Chandayot**. Responding to the Science Attitude Inventory (SAI) were 163 Native Americans and 52 non-Native Americans attending reservation secondary schools and 29 non-Native Americans attending non-reservation secondary schools. Differences among the three samples on total SAI scores and 3 of the 12 subscale scores led Haukoos and Chandayot to acknowledge the existence of three significantly different student populations and to suggest that racial-cultural and reservation-life factors affect science-related attitudes.

Interest in television stories and the relationship between interest and memory were investigated in two studies by **M. A. Shapiro**. In the first study, 150 college journalism students viewed three 90-second "Science Reports for Television" narrated by Don Herbert after which their perceived interest was tested. Four outcomes were measured: relevance, entertainment value, ease of understanding, and familiarity with the information. Eighty journalism students from another university participated in the second study. Here a fourth story was viewed, and items testing visual interest and unique quality were added to the instrument. Relevance and entertainment value, noted Shapiro, predicted most of the variance in the first and second study and accounted for most of the variance in interest in the second study.

9.42 What affective variables are related to achievement?

A longitudinal study conducted by **Oliver and Simpson** tested the influence of attitude toward science, achievement motivation, and science self-concept on science achievement. A sample of 3,902 students responded to investigator-developed, self-report instruments. Course grades measured achievement. The affective variables accounted for much variance in chemistry achievement of both eleventh (about 20%) and twelfth graders (more than 30%). Furthermore, students who scored two letter grades higher in science than in mathematics reported more positive attitudes toward science and higher self-concept, but only for years when the affective variables and achievement were measured concurrently. According to Oliver and Simpson, positive changes in student attitude will result in improved science achievement.

Relationships between Saudi and non-Saudi students' attitudes toward science and achievement in chemistry and physics were investigated by **Al-Shargi**. Data were collected from 334 male students enrolled in eight different secondary schools in Riyadh, Saudi Arabia, using an investigator-developed scale. Both Saudi and non-Saudi students have relatively negative attitudes toward science, although the attitudes of the Saudi males were significantly more positive than were those of the non-Saudi males. In science achievement, the non-Saudi males scored significantly higher on chemistry achievement than did Saudi males. Significant relationships were not found between attitude and achievement in chemistry and physics.

Woodson investigated the relationship of self-concept of learning, locus of control, and attitude toward science to science achievement. Junior high school students served as subjects, and data were collected using the Self-Concept as a Learner Scale, the Nowicki Locus of Control Scale, the Fraser Science Attitude Scale, and 12 unit tests from Merrill's Focus on Life Science . Data yielded no significant relationships between the various predictor variables and science achievement. However, Woodson found that girls have a higher level of internality in locus of control and more positive attitudes toward science than do boys.

Science students from 86 high school classes in upstate New York served as subjects in a study conducted by **Yurkewicz**. Tested were the relationships among student perception of teacher behaviors, science anxiety, and science achievement. Anxiety was assessed by items from Spielberger's State Trait Anxiety Inventory, and the newly developed Teacher Anxiety Related Behavior Assessment (TARBA) was used to measure student perceptions of teacher behaviors. Student perceptions of teacher behaviors were related to student anxiety toward science, and anxiety was negatively and significantly related to science achievement, noted Yurkewicz.

9.43 What teaching strategies enhance attitudes, interests, and other affective variables?

McCollum compared the effect of frog dissection and a lecture about frogs on students' attitudes and knowledge. Three hundred fifty biology students from five different high schools were randomly assigned to one of the two treatment groups. Students who were taught by the lecture method acquired significantly more knowledge about the frog. No group differences in attitude were recorded.

Olarewaju tested the effect of instructional objectives on 291 students' attitudes toward integrated science. Three classes of seventh grade students from three different Nigerian schools were randomly assigned to one of the three treatment groups. Two experimental groups were taught lessons from the Nigerian Integrated Science Project, with objectives presented before the lessons to one group but not to the other group. Students in the control group were taught the standard science lessons. The Students' Attitude

Questionnaire measured treatment effects. Both experimental groups, Olarewaju observed, were significantly more favorable toward integrated science than was the control group. In addition, the attitudes of students in the experimental groups receiving no instructional objectives were significantly more positive than were those of students presented with the instructional objectives.

Craig and Ayres investigated the influence of differing primary science experiences on the interest and achievement of boys and girls in secondary school science in Great Britain. The sample consisted of 342 fourth-year junior students from fifteen primary school classes. Four science interest questionnaires were administered when students left primary school and again at the completion of the students' first year of secondary school. Interviews and classroom observations supplemented interest scores. The findings revealed the following: the amount and type of primary school science was unrelated to student interest in science; female interest in science decreased following their first year of secondary school science; and, students' interest in primary school science was not predictive of science achievement during their first year of secondary school. Craig and Ayres concluded that factors related to teaching style and mode of presentation affect students' interest in science.

9.5 Instrumentation in the Affective Domain

9.51 What new instruments are available to assess affective concepts?

Krynowsky (b) utilized the Theory of Reasoned Action to guide the development of the Attitude toward the Subject Science Scale (ATSSS). The initial draft included 21 items concerned with students' performance of behaviors related to the teaching and learning of tenth grade science. The scale has a semantic differential format employing the same three bipolar adjective-pairs with all items: nice-awful; interesting-boring; and, pleasant-unpleasant. Based on feedback from researchers, teachers, and students the scale was revised and field-tested with tenth grade students. Test-retest coefficients ranged from .82 to .84, and internal consistency coefficients ranged from .89 to .96. Scale validity was tested by comparing students' scores on the ATSSS with their scores on the School Science scale ($r = .70$) and teacher rankings of the students' attitudes toward science ($r = .79$).

The attitude object of **Germann's** Likert scale was science as a school subject. The chosen attitude object was carefully differentiated from scientific attitudes, the scientific method, and the philosophy of science. Thirty-four statements, both negative and positive, made up the batch of trial items. Read and assessed for clarity and validity by three judges, 10 of the 34 original statements were dropped. The 24 remaining statements were submitted to 125 seventh and eighth grade students. Ten positive and four negative statements loaded on factor 1 in a factor analysis, and the 14 items accounted for 43.5 percent of the variance. Cronbach's alpha reliability r-value was found to be .93. Once in final form the 14-item scale was administered to four groups of biological and physical science students in grades 7 through 10. Again, all 14 items clustered on factor 1 and the percent of variance accounted for ranged from 59.6 to 69.8. Cronbach's alpha was .95 or higher, and item-total correlations ranged from .61 to .89. When submitted to two groups of subjects assumed to have different science attitudes, the scale behaved as predicted in one of two cases. The results on the attitude scale were correlated with semester course grade, four lab test scores, four SRA test scores, and four instruments well established in the literature to test cognitive development, biology content knowledge, and process and inquiry skills. In general, correlations were low but significant. Germann included the Attitude Toward Science in School Assessment instrument in the report.

Calhoun, Shrigley, and Showers designed a 20-item (and a shorter 6-item) Likert scale to test the attitudes of adults toward the use of nuclear energy to generate electricity. One hundred trial statements were written, each related to one of the subcomponents inherent in the attitude object. Two juries of nuclear energy experts analyzed and evaluated the authenticity of the seven (and later six) subcomponents. The 100 trial statements were administered to 41 secondary school students, and items were retained using three criteria: adjusted item-total correlation of at least .30; representation of items for each subcomponent; and, equal mix of negative and positive statements. Of the 100 items, 27 items were retained, and 9 new statements were added. The revised instrument was submitted to 873 adults representing four populations. Four tests were used to select the final 20 statements: the three tests mentioned above and evaluative quality. The range of item-total correlations for the 9 negative and 11 positive statements was .46 to .80, the inter-item mean r-value was .41, and the coefficient alpha was .93. Three of the four known group tests confirmed the construct validity of the pool of items. As predicted, males score higher than females. Subjects living closer to nuclear energy plants scored lower than those living farther away. Nuclear engineering students score higher than an anti-nuclear citizen's action group. Calhoun, Shrigley, and Showers observed mixed results in the number of science courses completed and the attitude score. A factor analysis further confirmed the validity of the scale. Six items make up a shorter version of the scale. The scale is included in the report.

9.6 Invited Commentary — Hugh Munby

I find that the review of attitude research in science education contains an underlying tension between two different theoretical and methodological approaches. In the simplest terms, the tension can be characterized as behaviorist versus cognitivist. I use these terms hesitantly, and I am sure that my use of the term "cognitivist" will strike many as odd because we are so accustomed to dividing evaluative enterprises into cognition and affective domains. These terms present a useful starting point for my argument. I begin by suggesting that we are in danger of being misled by the logical distinction between cognition and affect. Then, drawing upon some of the studies reviewed, I show that recent instrument design seems to be straddling uncomfortably a behaviorist and a cognitivist approach. The next step in my argument involves considering normative aspects of attitude research in science education. Specifically, I am interested in how we might answer a question like "Why do we do this research anyway?" This leads directly to some thoughts about directions that might be pursued.

A logical distinction that misleads. It is frustrating that the term "cognitive" is employed quite differently in two significant dichotomies: cognitive and affective, and cognitive and behavioral. The taxonomies that introduced the former dichotomy to educational discourse were initially the consequence of categorizing responses to test items according to their logical type based upon linguistic properties of the responses. The latter dichotomy, of course, is epistemological, and directs attention to what we view as probable, as important, and as worth studying. In a nutshell, behaviorism steers us away from asking questions about mental functioning, whereas cognitivism steers us right into asking these questions. The more behaviorist definition of attitude, then, encourages investigations of attitudes and their correlates, and this seems reflected in the wording of some section headings in the chapter, such as "What are gifted students' attitudes toward science?" and "What school and cultural factors are related to attitude, interest, and other affective variables?"

I find that the logical dichotomy between cognition and affect underlies parts of the work of Shrigley, Koballa, and Simpson. For instance, they are concerned about separating attitudes from beliefs and from opinion. I agree with them that the definition of attitude is highly complex, but I do not side with the need to maintain the separation of affect from cognition. The principal difficulty I have with this approach to conceptualizing "attitudes" is that it seems to move us away from something very fundamental: the possibility of recognizing that "attitudes" are mental and that we could benefit from recent developments in the study of cognition. It seems to me that there are distinct advantages to fixing on the cognitive status of attitudes. One of these concerns instrumentation, and another concerns the question "Why is attitude research done in science education?" These are considered below.

Measuring attitudes as if they were not cognitive. Some of the many problems endemic to instruments measuring attitudes to science (Munby, 1983) lie in ambiguities about the attitude object. Typically, scales allow one to report a single score, although some contain subscales, as if the concept "science" (or "my science course," "doing science," etc.) is a unitary and stable sort of thing, rather like a personality trait. Unfortunately, such scales appear to overlook two complexly interconnected issues. First, the meanings that respondents attach to the stems of items are likely to be different from those attached by the researchers. Meanings, of course, arise from a web of concepts, and there is no reason to suspect that one person's web will be the same as another's. Second, the typical approach seems to assume that the point at which the attitude measure is administered is immaterial. If an attitude is viewed as something stable and as distinct from something cognitive, then the assumption may be tenable. Yet if attitude responses are viewed as emanating from conceptual structures, which are in continual flux, then context becomes significant: attention would have to be paid to particular cognitive states.

Examples from recent studies are helpful. Olarewaju reports student attitudes in an integrated science course as if such an attitude is a trait that can summarize the variety of mental states prompted by all the features of the course. It is productive to contrast Olarewaju"s study with that of Craig and Ayres in which four different measures of interest in several specific science activities are used, suggesting that specific cognitive states are being explored.

In a sense, the deliberate inclusion of subscales in science attitude measures over the years is an implicit recognition that attitude objects need to be bounded precisely. Indeed, the successful validation of the "Nuclear Energy Attitude Scale" (Calhoun, et al.) might be due to the appropriate narrowing of the attitude object. This scale can be contrasted with Germann's, whose validity seems particularly dependent upon the meaning that each respondent attaches to the term "science."

Interestingly, the review mentions studies that appear to adopt a more cognitive view of attitude than is suggested by the review itself. For instance, Baker and Piburn use the variable "performance-based self-concept," and Kelly refers to perceptions of success and usefulness of the subject. Such concepts assume that students' responses are the consequence of cognitive processing. Furthermore, the concepts are consistent with recent notions of self-efficacy and academic self-concept as dynamic, subject-specific (or perhaps task-specific) cognitions (e.g., Marsh, Byrne, & Shavelson, 1988).

Why is attitude work done in science education? I was interested to note that neither the review nor any of the 1988 papers that I read offered a convincing case for studying attitudes to science. Presumably, such a case might be built on showing why it is important for youngsters to come to have positive attitudes to science. But "Because Science is there" (like taxes and the United Nations) doesn't seem to urge anyone to like it. So, the grounds for doing attitude research must be found elsewhere, and presumably they lie in instruction. As much research shows, self-concept in an academic area and achievement in that area are related; and, presumably, we are interested in learning how to help youngsters understand science and science subject matter. So, we might expect that studies in this area would be focusing upon particular relationships among specific instructional activities, students' understandings of specific scientific enterprises and content, and students' understandings of their competence and potential in these.

As can be seen from the review, some 1988 studies do not seem to be shedding new light on particular relationships between science instruction, attitudes, and achievement, except at a rather "macro" level. McCollum's comparison of frog dissection and lecturing about frog structure, and the cross-cultural study by Haukoos and Chandayot are examples. Suppose the field were characterized by qualitative and quantitative studies at a "micro" or cognitive level showing how particular and contained instances of instruction related to students' views of themselves interacting with specific science activities (classroom or otherwise), then the field's importance would be almost self-evident. Only a handful of the reviewed studies help the field in this way.

Moving attitude work back to the head. The seeming lack of attention to the interaction between instruction and cognitive processing in many of the papers mentioned in the review is a signal to me that the separation between the cognitive and the affective is interfering with progress in our field. I suggest that a more productive avenue lies in discarding the "attitude as trait" stance, and in assuming an "attitude as cognitive state" position. White and Tisher (1986) refer to the tension between state and trait in their review (p. 892). Interestingly, the index of the 1986 Handbook of Research on Teaching gives just three page references under "attitude": two are to the chapter by White and Tisher, the other is to "attitudes to computers." The concept "attitude" has been supplanted in other areas by "self-efficacy," "attributions," etc..

Moving the concept of attitude from trait to state demands that attitudes be seen as specific components of an intricately connected web of constructs that a youngster might hold about all manner of scientific phenomena and beliefs. It demands applying a model of beliefs, such as Nespor's (1987), to youngsters' discourse about science, possibly obtained through interviews. Also, it demands that we obtain a better understanding of the networks of concepts that children hold about science and scientific phenomena—Bloom's (in press) work is an example. Last, it demands a rejection of a behavioral orientation to attitudes. By this, I mean that we should feel free to do the following:

1. Abandon theoretical approaches that dichotomize "affective" and "cognitive."
2. Set aside research approaches that correlate such variables as achievement and motivation with gross attitude measures.

3. Focus on how youngsters think of themselves as actors in specific science and science classroom activities.
4. Attempt work that will shed light on the cognitive processing of youngsters as they come to grips with science, and connect this work to the so called "misconceptions" literature.

References

Bloom, J. (in press). Context of meaning: Young children's understanding of biological phenomena. International Journal of Science Education.

Marsh, H., Byrne, B., & Shavelson, R. (1988). A multifaceted academic self-concept: Its hierarchical structure and its relation to academic achievement. Journal of Educational Psychology, 80, 366-380.

Munby, H. (1983). An investigation into the measurement of attitudes in science education. Columbus, OH: SMEAC Information Reference Center, Ohio State University.

Nespor, J. (1987). The role of beliefs in the practice of teaching. Journal of Curriculum Studies, 19, 317-328.

White, R., & Tisher, R. (1986). Research on natural sciences. In M. Wittrock (Ed.), Handbook of research on teaching (3rd. ed.), (pp. 328-375). New York: Macmillan.

10.0 Epistemology

The nature of science, its effect on classroom teaching, and world views of science manifested by teachers and students are of concern to science educators. Understanding the nature of science is the dependent variable in numerous studies considered in the 1988 Review. In this concluding chapter, studies dealing with the nature of science (6 studies) and world views of science (2 studies) are reviewed. In the nature of science section, science educators with expertise in the history and philosophy of science speak out; the inductivist view of science and scientism are critiqued; and, Pepper's four epistemological orientations are applied to classroom teaching and supervision. In the final section, the world views of science teachers and students are chronicled.

10.1 Nature of Science

10.11 What ideologies should undergird instruction and curricula development?

Hodson argued that curriculum development and teaching practices in the classroom are thwarted by teachers who operate under principles of science that philosophers have long since considered inadequate. An example is the inductivist view of science. Simple, unbiased student observations are the heartbeat of discovery science. From observations students are expected to inductively spawn science generalizations. Here the student, free of biases, records facts objectively, it is claimed. Observing and generalizing are important skills for students to learn. But to assume that unbiased observations lead infallibly to conceptual explanations is neither good science nor good psychology. First, scientists bring speculation to an observation. Second, learning theorists insist that new knowledge must be firmly anchored in a learner's prior knowledge. Hodson raises more questions. Implicit in modem science curricula is a generalized scientific method that can be taught in the science classroom. Yet contemporary philosophers of science fail to support the assumption. Also, science process seems to have priority over content; or, at least, process commonly precedes concepts in curriculum thought. How can this be when real science supports a dynamic relationship between process and content? Recent psychological thought supports the premise that existing knowledge determines the processes needed to generate further knowledge; in which case, content drives process. Hodson delineates the role of theory in classroom teaching; the scientific method is redefined. Proposed is a three-stage science curriculum based on the Kuhnian model. Twelve goals for teaching science that would make for a more pedagogically valid curriculum are advanced for the reader.

Duschl claimed that precollege science is dominated by an authoritarian view, one where scientific knowledge is considered absolute and final. The source of this view is scientism, a belief rooted in logical positivism and related philosophies developed during the first half of the twentieth century.

Its immunity to criticism rests, in part, upon its presupposition that the only valid critique of the nature of science is one that is scientifically based. Therefore, any conclusions drawn from the history of science about the nature of science are parlayed as subjective rather than objective, a non-issue to logical positivists. Two characterizations of science are described. One, supported by scientism, is the process of justifying knowledge. The other is the process of discovering and generating knowledge. The first deals with the what of science, and it rests on logical and empirical criteria. The latter, how science has arrived at such knowledge, rests on historical and sociological criteria. Therefore, Duschl maintains, precollege science, especially for the non-science major, must attend to humanistic and social issues in addition to the facts of science. Historians, sociologists and philosophers must have a stake in science curriculum design, implementation, and evaluation, an enterprise now guided by professional scientists mainly influenced by scientistic ideologies, according to Duschl.

Geddis developed an overall scheme of knowledge that consists of three parts: knowledge of ideology, ideology of teaching, and intellectual context of instruction. Central to this report was a classroom vignette where an experiment "did not work." When students reported their observations — the silver chloride failed to darken — the teacher discredited their observations and scolded them for not observing more carefully. (The author who witnessed the investigation also failed to observe any change.) Thus, students were taught to rely on the teacher's traditional position of authority rather than their own observations and reasoning. Drawing upon the work of Pepper, Geddis described for teachers and supervisors four epistemological orientations from which pedagogical principles can be generated and used in the classroom: formism, mechanism, contextualism, and organicism. He illustrated how our science teacher fell back on formism, whereas a plan involving mechanism would have sacrificed less independence of thought on the part of students. The use that supervisors might make of the epistemological orientations in counseling science teachers is carefully illustrated.

10.12 What is the valid pedagogical role of "description" and "explanation" in the classroom?

Drawing upon the work of Bateson, Martin, and Weaver, **Horwood** distinguished between the terms "describe" and "explain" and classroom activities associated with the terms. A description is information, isolated, and without a network of relatedness. An explanation has information with connections, a relationship built on a system of logical causality. Even more central to the understanding of the nature of science is the distinction made between explaining a thing and explaining a thing to someone. The former is useful in a research context. A truthful and rational report is its mission, not necessarily understanding on the part of a listener or reader. Explaining something to someone else is pedagogical. Here the teacher is at work promoting understanding for students. Is the science teacher not held to the same conditions of truth as the researcher? The teacher may abridge, omit or even falsify an account, it is suggested, in order that the student may understand a concept and derive satisfaction. But the teacher's explanation must move the student closer to a correct understanding, and the liberties taken must not block future learning. How far, then, can teachers stray from scientific orthodoxy and retain valid pedagogical principles? Horwood described the faulty usage of description and explanation now common in the science classroom. Several curriculum options are explored.

10.13 What are some of the functional paradigms operating in the classroom setting?

Tomkiewicz investigated how biology teachers function in four areas of educational endeavor: teaching, learning, curriculum, and governance. The study centered around the teaching of genetics. Twenty-eight teachers participated; and, interviews, field notes, and several inventories provided a data base. Interpretive analysis revealed paradigms operating in all four areas. The paradigms are reviewed, in part: continued learning is necessary for teachers to remain current in their knowledge of content; teachers and students need an understanding of the nature of science and the interdisciplinary nature of curricula; the controversy in genetics stimulates student interest, which, in turn, provides them with a better understanding of themselves; meaningful learning enhances the ability of students to deal with misinformation and misconceptions; and, autonomy in curriculum matters is important to teachers.

In a set of five papers, **Crocker, Bannister, Dodd, and Benfield** sought functional paradigms operating within science curricula as manifested in school documents and interpreted by teachers. The analysis centered around teacher repertoires, orchestrating the setting, content coverage, and evaluation. Teaching content in a whole class setting was the dominant paradigm. Teaching science as a process, a secondary paradigm, required a change in the dominant pattern.

10.2 World View

10.21 How are world views of science manifested by teachers and students?

Using an analytical scheme developed by Kilbourn, **Proper, Wideen, and Ivany** investigated the world view projected by teachers of biology, physics, chemistry, and earth science. The teachers' classroom discourse analyzed in this study were drawn from a bank of 65 audiotaped lessons. Results revealed that mechanism is dominant in physics and chemistry, and that biology advanced the broadest spread of world views (vis., formism, mechanism, contextualism). Also noted were links to content areas within subjects. Formism was conveyed when objects were classified or comparisons were made in all subject areas. Atomic or kinetic theory in physics and chemistry and genetics in biology led to projections of mechanism. Contextualism was gauged in terms of beliefs about human opinions or constructs, and organicism was projected by descriptions of interrelated systems in biology and earth science. Generally, world views were not openly projected by the teachers, but through implication or assumption.

Ledbetter identified the world views toward science of teachers and students in a pilot study and confirmed them using data generated by a questionnaire administered to 60 teachers and 580 eighth grade students. In part, the beliefs identified by Ledbetter are summarized here: students consider natural phenomena important, and teachers prefer experimentation; student learning does not match teacher perception of their learning; the world views articulated by teachers fail to match their observed behavior in the classroom; teachers are unaware of students' definition of science, and neither are students aware of the teacher's definition; female students consider science less important than do males; and, teachers are unaware that students prefer discovery investigations over laboratory exercises in which verification prevails.

10.22 Can world view research facilitate the understanding of misconception research?

Cobern argued that misconception research results can lead us to believe that students come to science class with a rather homogeneous view of the world. Such an assumption, according to Cobern, denies us a more comprehensive understanding of factors that bring about higher achievement and positive attitudes toward science. In this study, Michael Kearney's model of world view is applied to misconception research. A second section of the report deals with world view instrumentation.

10.3 Invited Commentary — Richard Duschl

The application of epistemological frameworks to science education has a storied past in recent decades. Two of the more influential and widely read works in modern science education are those by Jerome Bruner (1960), The Process of Education, and Joseph Schwab (1962), 'The teaching of science as inquiry'. A common denominator between these two classics of science education is their mutual recognition of discipline structures existing within the science subjects we teach. At a first approximation, this structure is represented as the language of science. In modern terms, this structure constitutes the declarative and procedural knowledge and epistemological frameworks inherent in the sciences.

Schwab (1962) held that each discipline of science has a substantive and syntactical structure. He also proposed that scientists use these structures to conduct two types of inquiry—stable inquiry and fluid inquiry, a view quite consistent with Kuhn's (1970/1962) notion of normal and revolutionary science. What distinguishes Bruner's and Schwab's views of the structure of science, then, from contemporary perspectives is the present articulation of details that seek to explain the developmental processes of theory discovery, restructuring, and replacement.

In the thirty-odd years since Jerome Bruner, a cognitive scientist, and Joseph Schwab, a biologist/philosopher of science turned curriculum specialist, first began to put forth views which would come to influence generations of science educators, we have witnessed an amalgamation of the disciplines of cognitive science and epistemology. New views about the nature of science (i.e., Giere, 1988; Laudan, 1984) which seek to explain the growth and development of scientific knowledge have embraced tenets from cognitive science. Likewise, cognitive scientists investigating the growth of knowledge in children and adult learners (i.e., Carey, 1985; Resnick, 1983) find it prudent to employ epistemological tenets from the history and philosophy of science to guide their investigations. A new domain of science education research has been forged.

Hodson captures the importance of this merger between psychology on the one hand and epistemology on the other hand when he points out that it is now possible to have "harmony between the philosophical and psychological principles underpinning the curriculum" (p. 28). The argument for harmony rests on two premises: first, that contemporary investigations in psychology and epistemology are focusing on understanding mechanisms that explain the restructuring of knowledge, and second, that each discipline has come to fully recognize the important role of prior knowledge or theoretical commitment to the process of restructuring.

The contributions of history of science to philosophy of science and cognitive science to educational psychology have pushed investigators in cognitive science, history of science, and philosophy of science to explore criteria for establishing a context of discovery. This quest for explicating the central role that theories and prior knowledge have in science and in knowing has rekindled researchers' interest in examining how worldviews (Cobern; Geddis; Ledbetter; Proper, Wideen, & Ivany) and epistemological frameworks (Duschl, 1988; Horwood) might affect the growth and development of scientific knowledge in learners.

Thus, new understandings in epistemology about the role of theories in knowledge growth, and in cognitive science about the role of prior knowledge in learning, generates significant implications for educational policy. Grandy (1988) and Hamilton (1988), for example, question the extent to which epistemological frameworks can be used as procedural knowledge guidelines in science instruction. Grandy (1988) writes,

> . . . (O)ne of the important lessons to be learned from both cognitive science and history of science is that the rules by which scientists apply theory to experimental situations and the rules by which they evaluate

> modifications of theory are quite deeply implicit. The rules are internalized in the process of learning the domain-specific knowledge of the science but are not explicit. (Grandy, 1988, p. 1)

Thus, Grandy questions the extent to which history of science can be relevant to contemporary learners since the prior knowledge schemata of our scientific forebearers is quite different from our modern scientific neophytes.

Hamilton (1988) also questions the extent to which a context of discovery borne out of the history and philosophy of science can assist learners to acquire a new conceptual structure or induce conceptual change. Blending the notions of context of discovery from epistemology with the notions of schema and knowledge structures from cognitive science, he maintains, fails to address the basic psychological processes involved in the use of this knowledge.

> Presenting the context of discovery should be very useful for the development of scientific theory schema but contribute little to the development of scientific process schema. By presenting the historical context and problems that were responsible for the initial development of a scientific theory, one is focusing primarily on the acquisition (encoding) of facts, events and a conceptual structure that relates to the target theory or theories. As indicated above, this ignores the development of the scientific process schema and, hence, the retrieval and use of appropriate scientific knowledge. (Hamilton, 1988, p.5)

One proponent for the use of history of science as a guide for the selection and sequence of science instruction is Nersessian (1989). Her detailed work (Nersessian, 1987) on the cognitive steps taken by physicists in the development of electromagnetic theories serves as an example of the type of research by historians and philosophers of science that has relevance for science education. Another example of how historical studies can inform science education is the work of Shapin (1989) on the role of experiments at the Royal Academy of Science in London. In detailing the activities of Robert Boyle and his assistant Robert Hooke, we are introduced to how private knowledge becomes public knowledge in a scientific community. So, too, does Giere's (1988) work on the cognitive analysis of twentieth century theory development help us identify procedural guidelines of knowledge growth. Employing ethnographic techniques, time is spent in labs with scientists to grasp the cognitive factors and sociological conditions that describe the growth of scientific knowledge. The efforts of Nersessian, Shapin, and Giere are examples of some of the fine work being carried out by historians and philosophers of science that have relevance for science education researchers.

Duschl, Hamilton, and Grandy (1989) consider the implications of joining psychology with epistemology and conclude that there is a fair amount of fundamental research that needs to be done to resolve tensions between the two disciplines.

> The partitioning of learning processes, for example, into encoding/retrieval categories, scientific knowledge into declarative/procedural components, and processes of scientific knowledge growth into discovery and testing contexts presents a more accurate description of what occurs in the growth of knowledge. But when we consider that each of these paired sets of terms would be applied differently depending on the science content or context being employed, then and only then do we truly begin to grasp the complexity of the task we face. (p. 25)

The synthesis of cognitive psychology with epistemology requires that we consider how domain-specific guidelines would affect educational practice. In short, we need a better qualitative sense of the academic work of our classrooms like that reported by Doyle (1984), Leinhardt and Greeno (1986), Leinhardt and Putnam (1987), Tobin and Gallagher (1987), and in the present review by Crocker, Bannister, Dodd, and Banfield and Tomkiewicz. Research questions that emerge concerning the application of epistemological frameworks to science education include (Duschl et al., 1989):

- How do teachers' beliefs about the nature of science affect the intended curriculum?
- How should teacher decision-making be guided to insure that the translated curriculum reflects the intended curriculum?
- What are the decision-making strategies which emerge from our synthesis of epistemology and psychology?
- How might these strategies be integrated effectively into the repertoire of the classroom teacher?
- What combination of the contribution of cognitive science and epistemological frameworks is best in helping students learn science and teachers teach science?
- Should this combination vary with each change in specific content domain of knowledge or should it remain invariant?
- Are teachers capable of using multiple and complex sets of instructional heuristics?
- Can we identify the appropriate heuristics and strategies that would allow students to access and employ their knowledge in appropriate situations?
- How will these procedures differ for contexts of discovery and justification?
- Can philosophers and historians of science develop more cognitively-oriented accounts of the development of scientific theories?

- Can philosophers of science come to considerably more agreement on the epistemological rules teachers ought to employ in the teaching of science?

Answers to these questions will emerge from the interfield investigations conducted by educational researchers, cognitive scientists, and historians and philosophers of science. Science education researchers interested in examining questions such as these are advised to expand the scope of their literature reviews to these cognate areas.

References

Bruner, J. (1960). The process of education. Cambridge, MA: Harvard University Press.

Carey, S. (1985). Conceptual change in childhood. Cambridge, MA: Bradford Books, MIT Press.

Doyle, W. (1984). Academic work. Review of Educational Research, 53, 159-199.

Duschl, R. (1988). Scientific theory as schema: An epistemological perspective. Paper presented at the annual meeting of the American Educational Research Association, New Orleans, April, 1988.

Duschl, R., Hamilton, R., & Grandy, R. (1989). Psychology and epistemology: Match or mismatch when applied to science education. Paper presented at the International conference "Philosophy of science and science education" at Florida State University, Tallahassee, November 5-9, 1989.

Giere, R. (1988). Explaining science: A cognitive approach. Chicago: The University of Chicago Press.

Grandy, R. (1988). Cognitive schemas, epistemology and science education: A perspective from philosophy of science. Paper presented at the annual meeting of the American Educational Research Association, New Orleans, April, 1988.

Hamilton, R. (1988). Schema as scientific theory: A psychological perspective. Paper presented at the annual meeting of the American Educational Research Association, New Orleans, April 1988.

Kuhn, T. (1970/1962). The structure of scientific revolutions (2nd ed.). Chicago: University of Chicago Press.

Laudan, L. (1984). Science and values. Berkeley, CA: University of California Press.

Leinhardt, G., & Greeno, J.G. (1986). The cognitive skill of teaching. Journal of Educational Psychology, 78(2), 75-95.

Leinhardt, G., & Putnam, R.T. (1987). The skill of learning from classroom lessons. American Educational Research Journal, 24(4), 557-587.

Nersessian, N. (Ed.) (1987). The process of science: Contemporary philosophical approaches to understanding scientific practice. Dorcrecht: Martinus Nijhoff Publishers.

Nersessian, N. (1989). Conceptual change in science and in science education. Synthesis, 80(1), 163-183.

Resnick, L. (1983). Mathematics and science learning: A new conception. Science, 220, 477-478.

Schwab, J. (1962). The teaching of science as inquiry. In J. Schwab & P. Brandewein (Eds.). The teaching of science. Cambridge: Harvard University Press.

Shapin, S. (1987). The house of experiments in seventeenth-century England. ISIS, 79, N 298.

Tobin, K., & Gallagher, J. (1987). What happens in high school science classrooms? Journal of Curriculum Studies, 19, 549-560.

References

Abayomi, B. I. (1988). The effect of concept mapping and cognitive style on science achievement (Doctoral dissertation, Georgia State University, 1988). Dissertation Abstracts International, 49(6), 1420-A.

Abbott, M. M., & Lisa-Johnson, B. (1988). Citywide results of the New York City 1987 science survey grades 5 and 8. Office of Educational Assessment Research and Development Report. (ERIC Document Reproduction Service No. ED 295 848)

Abimbola, I. O. (1988). The problem of terminology in the study of student conceptions in science. Science Education, 72(2), 175-184.

Abu Bakar, K. H., Rubba, P. A., Tomera, A. N., & Zurub, A. R. (1988). Jordanian and Malaysian science teachers' prominent perceived professional needs: A comparison. Journal of Research in Science Teaching, 25(7) 573-587.

Adams, D. D., & Shrum, J. W. (1988). The effects of microcomputer-based laboratory exercises on the acquisition of line graph construction and interpretations skills by high school biology students. Paper presented at the annual meeting of the National Association for Research in Science Teaching, Lake of the Ozarks, April, 1988. (ERIC Document Reproduction Service No. ED 292 652)

Ahmed, Q. R. (1988). An evaluation of practical work at intermediate stage in biology in Pakistan with special reference to science process skills (Doctoral dissertation, University of Keele, U. K., 1987). Dissertation Abstracts International, 49(1), 67-A.

Aikenhead, G. S. (1988). An analysis of four ways of assessing student beliefs about STS topics. Journal of Research in Science Teaching, 25(8), 607-629.

Akindehin, F. (1988). Effect of an instructional package on preservice science teachers' understanding of the nature of science and acquisition of science-related attitudes. Science Education, 72(1), 73-82.

Al Methen, A. E., & Wilkinson, W. J. (1988). In support of a sociological explanation of sex differences in science and mathematics achievement: Evidence for a Kuwaiti study of secondary science certificate examinations. Research in Science and Technological Education, 6(1), 91-101.

Al-Shargi, M. R. (1988). Saudi and non-Saudi Arab male students' attitudes toward science and science achievement in secondary schools (Doctoral dissertation, Oregon State University, 1987). Dissertation Abstracts International, 49(3), 472-A.

Alao, D. A., & Gallagher, J. J. (1988). Influences of examination policies on chemistry teaching practices in Nigerian high schools: An ethnographic study. Paper presented at the annual meeting of the National Association for Research in Science Teaching, Lake of the Ozarks, April, 1988. (ERIC Document Reproduction Service No. ED 292 615)

Alick, B., & Atwater, M. M. (1988). Problem-solving strategies and the success of Afro-American science majors. School Science and Mathematics, 88(8), 659-665.

Ameh, C. O., & Gunstone, R. F. (1988). The understanding held by Nigerian science teachers of some science concepts. Paper presented at the Annual Meeting of the American Educational Research Association, New Orleans, LA, April, 1988. (ERIC Document Reproduction Service No. ED 292 633)

Amigues, R. (1988). Peer interaction in solving physics problems: Sociocognitive confrontation and metacognitive aspects. Journal of Experimental Child Psychology, 45(1), 141-158.

Ault, C. R., Novak, J. D., & Gowin, D. B. (1988). Constructing vee maps for clinical interviews on energy concepts. Science Education, 72(4), 515-545.

Baird, W. E., & Koballa, T. R., Jr. (1988). Changes in preservice elementary teachers' hypothesizing skills following group and individual study with computer simulation. Science Education, 72(2), 290-223.

Baker, C. A. (1988). A comparison of student-directed and teacher-directed modes of instruction for presentation of density to high school chemistry students (Doctoral dissertation, Purdue University, 1987). Dissertation Abstracts International, 49(5), 1107-A.

Baker, D. R., & Piburn, M. D. (1988). Learning to think: A major factor in the decline in attitudes toward science. Paper presented at the annual meeting of the National Association for Research in Science Teaching, Lake of the Ozarks, MO, April, 1988. (ERIC Document Reproduction Service No. ED 291 547)

Bar-Lavie, B. (1988). Enhancing meaningful learning in an environmental education program: A case study of a class empowered through the use of Novak's and Gowin's principles of learning how to learn, concept mapping, interviewing, and educating (Doctoral dissertation, Cornell University, 1987). Dissertation Abstracts International, 48(10), 2590-A.

Barman, C. R. (1988). Assessing the effectiveness of instructional materials designed for elementary science methods students. Paper presented at the annual meeting of the National Association for Research in Science Teaching, Lake of the Ozarks, MO, April, 1988. (ERIC Document Reproduction Service No. ED 294 728)

Barnes, M. B., & Conklin, K. (1988). A review of memory systems and implications for research into the learning process. Paper presented at the annual meeting of the National Association for Research in Science Teaching, Lake of the Ozarks, April, 1988. (ERIC Document Reproduction Service No. ED 292 658)

Barrington, B. L., Hendricks, B. (1988). Attitudes toward science and science knowledge of intellectually gifted and average students in third, seventh, and eleventh grades. Journal of Research in Science Teaching, 25(8), 679-687.

Barrow, L. H. (1988). Professional preparation, course content, and responsibilities of New England's secondary science methods faculty. Science Education, 72 (5), 585-595.

Benbow, A. E. (1988). A comparison of the effectiveness of demonstrations, verbal statements, and hands-on experiences on correcting a misconception of first-graders regarding magnets (Doctoral dissertation, University of Maryland College Park, 1987). Dissertation Abstracts International, 48(9), 2301-A.

Bitner-Corvin, B. L. (1988). Is the GALT a reliable instrument for measuring the logical thinking abilities of students in grades six through twelve? Paper presented at the Annual Meeting of the National Association for Research in Science Teaching, Lake Ozark, MO, April, 1988. (ERIC Document Reproduction Service No. ED 293 716)

Blank, R. K. (1988a). Improving research on teacher quality in science and mathematics: Report of a symposium of scientists, educators, and researchers. Journal of Research in Science Teaching, 25(3), 217-224.

Blank, R. K. (1988b). State network for indicators of science and mathematics education. Paper presented at the annual meeting of the American Educational Research Association, New Orleans, April, 1988. (ERIC Document Reproduction Service No. ED 293 708)

Blom, K. G. (1988). Effects of instruction in controlling variables on biology students in transition between concrete and formal stages (Doctoral dissertation, State University of New York at Albany, 1988). Dissertation Abstracts International, 49(6), 1420-A.

Bloom, J. W. (1988). Cognitive strategies used by high school students in solving biological identification tasks (Doctoral dissertation, University of Houston, 1987). Dissertation Abstracts International, 49(5), 1107-A.

Bounds, C. L., & Nicholls, G. M. (1988). Nuffield physics for the average pupil: An evaluation of a CSE course and some implications for GCSE. School Science Review, 69(248), 477-482.

Boyd, V., Carstana, S., Hunt, P., Hunt, S., Magoon, T., McDevitt, J., McLaran, B., & Spokane, A. (1988). Audiotutorial tapes as aids to college chemistry registrants. Research report #10-87. (ERIC Document Reproduction Service No. ED 294 716)

Braathen, P. C., & Hewson, P. W. (1988). A case study of prior knowledge, learning approach and conceptual change in an introductory college chemistry tutorial program. Paper presented at the Annual Meeting of the National Association for Research in Science Teaching, Lake Ozark, MO, April, 1988. (ERIC Document Reproduction Service No. ED 292 687)

Brasell, H. M. (1988). Effectiveness of a microcomputer-based laboratory in learning distance and velocity graphs (Doctoral dissertation, University of Florida, 1987). Dissertation Abstracts International, 48(10), 2591-A.

Brasil, R. J. (1988). Comparison of two teaching strategies for introducing thermochemistry (Doctoral dissertation, University of Illinois at Chicago, 1987). Dissertation Abstracts International, 48(11), 2843-A.

Brody, M., Chapman, E., & Marion, S. (1988). An assessment of student knowledge in fourth, eighth, and eleventh grades of science and natural resource concepts related to acidic deposition. (ERIC Document Reproduction Service No. ED 291 551)

Brooks, D. W. (1988). The teaching of organic chemistry in schools—can we learn from the Kenyan experience? School Science Review, 69(248), 575-578.

Brown, C. L. (1988). The development and evaluation of a model course in advanced biology for secondary education (Doctoral dissertation, North Carolina State University, 1987). Dissertation Abstracts International, 48(8), 2034-A.

Brown, D. E. (1988). Using analogies and examples to help students overcome misconceptions in physics: A comparison of two teaching strategies (Doctoral dissertation, University of Massachusetts, 1987). Dissertation Abstracts International, 49(3), 473-A.

Browning, M. E. (1988). The effects of meiosis/genetics integration and instructional sequence on college biology student achievement in genetics. Paper presented at the annual meeting of the National Association for Research in Science Teaching, Lake of the Ozarks, MO, April, 1988. (ERIC Document Reproduction Service No. ED 291 578)

Browning, M. R., & Lehman, J. D. (1988). Identification of student misconceptions in genetics problem solving via computer program. Journal of Research in Science Teaching, 25(9), 747-761.

Brunkhorst, B. J. (1988). Exemplary middle and junior high science programs: An assessment of teacher characteristics and student outcomes (Doctoral dissertation, University of Iowa, 1987). Dissertation Abstracts International, 48(10), 2591-A.

Butzow, J. W. (1988). Mainstreaming computers in science and mathematics education: A two year study. (ERIC Document Reproduction Service No. ED 291 594)

Calhoun, L., Shrigley, R. L., & Showers, D. E. (1988). Designing the nuclear energy attitude scale. Science Education, 72(2), 157-174.

Calkins, J. R. (1988). Marine education through videos: The wave of the future? Journal of Marine Education, 8(3), 10-12.

Callison, B. F. (1988). Comparison of two approaches in teaching general science courses: Four-fold or traditional (Doctoral dissertation, Brigham Young University, 1987). Dissertation Abstracts International, 48(10), 2591-A.

Carey, S., Evans, R., Honda, M., Jay, E., & Unger, C. (1988). What junior high school students do, can, and should know about the nature of science and scientific inquiry. Technical Report 88-2. (ERIC Document Reproduction Service No. ED 295 833)

Carlsen, W. S. (1988). The effects of science teacher subject-matter knowledge on teacher questioning and classroom discourse (Doctoral dissertation, Stanford University, 1988). Dissertation Abstracts International, 49(2), 194-A.

Carrie, J. (1988). The growth of the concept of energy—a longitudinal study in Scottish secondary schools (Doctoral dissertation, University of Glasgow, 1984). Dissertation Abstracts International, 49(3), 473-A.

Carter, C. S. The role of beliefs in general chemistry problem solving (Doctoral dissertation, Purdue University, 1987). Dissertation Abstracts International, 49(5), 1107-A.

Chandavarkar, M. I. C. (1988). Physics in United States schools (Doctoral dissertation, Columbia University Teachers College, 1988). Dissertation Abstracts International, 49(6), 1421-A.

Charron, E. H. (1988). Influences of classroom and community on youths' understandings of science (Doctoral dissertation, University of Georgia, 1987). Dissertation Abstracts International, 48(11), 2843-A.

Chen, Q. (1988). Computer education in secondary schools in the People's Republic of China. Journal of Research in Science Teaching, 25(6), 493-500.

Chi, M. T., & Bassok, M. (1988). Learning from examples via self-explanations. Technical Report No. 11. (ERIC Document Reproduction Service No. ED 296 879)

Cobern, W. H. (1988). World view and misconception research. Paper presented at the annual meeting of the National Association for Research in Science Teaching, Lake of the Ozarks, MO, April, 1988. (ERIC Document Reproduction Service No. ED 292 676)

Constant, T. L. (1988). MIcrocomputer simulations and the acquisition of motion physics concepts and integrated process skills (Doctoral dissertation, University of Houston, 1987). Dissertation Abstracts International, 48(8), 2035-A.

Consuegra, G. F. (1988). The prediction of performance in seventh grade gifted science classes from components of gifted identification and selection procedures and certain science-related factors (Doctoral dissertation, University of Maryland, 1987). Dissertation Abstracts International, 48(10), 2591-A.

Contreras, A. (1988). Constructing subject matter in high school physics: An ethnographic study of three experienced physics teachers (Doctoral dissertation, Michigan State University, 1988). Dissertation Abstracts International, 49(5), 1045-A.

Costello, S. J. (1988). The relationship of problem solving abilities in genetics to encoding and combining propositions concerning disjunctive reasoning (Doctoral dissertation, Rutgers, The State University of New Jersey-New Brunswick, 1987). Dissertation Abstracts International, 48(9), 2301-A.

Craig, J., & Ayres, D. (1988). Does primary science affect girls' and boys' interest in secondary science? School Science Review, 69(248), 417-426.

Crawley, F. E. (1988). Determinants of physical science teacher's intentions to use investigative teaching methods: A test of the the theory of reasoned action. Paper presented at the annual meeting of the National Association for Research in Science Teaching, Lake of the Ozarks, MO, April, 1988. (ERIC Document Reproduction Service No. ED 292 675)

Crocker, R. K., Bannister, C., Dodd, J., & Banfield, H. (1988). Curriculum translation in secondary school science: An analysis of teacher functional paradigms. Paper presented at the annual meeting of the National Association for Research in Science Teaching, Lake of the Ozarks, MO, April, 1988. (ERIC document Reproduction Service No. ED 294 765)

Crosby, G. L. (1988). Qualitative chemical equilibrium problem solving: College student conceptions (Doctoral dissertation, University of Maryland College Park, 1987). Dissertation Abstracts International, 48(8), 2035-A.

Crosby, J. T. (1988). A study of the relationships among science teacher performance as measured by the Florida Performance Measurement System, student task engagement and student achievement in regular and laboratory classroom settings (Doctoral dissertation, University of South Florida, 1987). Dissertation Abstracts International, 48(10), 2523-A.

Curtis, S., & Millar, R. (1988). Language and conceptual understanding in science: A comparison of English- and Asian-language-speaking children. Research in Science and Technological Education, 6(1), 61-77.

De Jong, E. J., & Gunstone, R. F. (1988). A longitudinal classroom study of mechanics concepts and conceptual change. Paper presented at the Annual Meeting of the National Association for Research in Science Teaching, Lake Ozark, MO, April, 1988. (ERIC Document Reproduction Service No. ED 291 580)

Dierking, L. D. (1988). Parent-child interactions in a free choice learning setting: An examination of attention-directing behaviors (Doctoral dissertation, University of Florida, 1987). Dissertation Abstracts International, 49(4), 778-A.

Dori, Y., Hofstein, A., & Samuel, D. (1988). The development and evaluation of a chemistry curriculum for nursing schools in Israel. Paper presented at the annual meeting of the National Association for Research in Science Teaching, Lake of the Ozarks, MO, April, 1988. (ERIC Document Reproduction Service No. ED 292 612)

Dufresne, R. J. (1988). Problem solving: Learning from experts and novices. (ERIC Document Reproduction Service No. ED 294 752)

Duschl, R. A. (1988). Abandoning the scientistic legacy of science education. Science Education, 72(1), 51-62.

Eleuterius, C. K. (1988). Learning styles of marine scientists (Doctoral dissertation, The University of Southern Mississippi, 1987). Dissertation Abstracts International, 49(4), 698-A.

Ellis, J. D., & Kuerbis, P. J. (1988). A model for implementing microcomputers in science teaching. Paper presented at the annual meeting of the National Association for Research in Science Teaching, Lake of the Ozarks, April, 1988. (ERIC Document Reproduction Service No. ED 292 655)

Ellse, M. (1988). Transferring not transforming energy. School Science Review, 69(248), 427-437.

Eltinge, E. M., & Glass, L. W. (1988). Meeting modern science education goals through partnerships. School Science and Mathematics, 88(1), 16-23.

Esquivel, J. M, & Brenes, M. (1988). Gender differences in achievement in Costa Rican students: Science, mathematics, and Spanish. Paper presented at the annual meeting of the National Association for Research in Science Teaching, Lake of the Ozarks, MO, April, 1988. (ERIC Document Reproduction Service No. ED 292 637)

Eves, R. L., & Davis, L. E. (1988). Is the rock cycle and outdated idea, or a unifying concept? Journal of Geological Education, 36(2), 8-10.

Farrell, E. (1988). How teaching proportionality affects transfer of learning: Science and math teachers need each other. School Science and Mathematics, 88(8), 688-695.

Feher, E., & Rice, K. (1988). Shadows and anti-images: Children's conception of light and vision. Science Education, 72(5), 637-649.

Feldsine, J. E. (1988). The construction of concept maps facilitates the learning of general college chemistry: A case study (Doctoral dissertation, Cornell University, 1987). Dissertation Abstracts International, 48(9), 2301-A.

Finegold, M., & Raphael, D. (1988). Physics in Canadian secondary schools: Intentions, perceptions, and achievement. Journal of Research in Science Teaching, 25(4), 293-315.

Finson, K. D., & Enochs, L. G. (1988). A survey of the status of earth science in Kansas schools. Science Education, 72(1), 83-92.

Flower, D. R. (1988). An investigation of science process skills hierarchies with learning disabled and non-disabled subjects (Doctoral dissertation, University of Cincinnati, 1987). Dissertation Abstracts International, 48(8), 1969-A.

Fortner, R. W., & Mayer, V. J. (1988). Ocean and Great Lakes awareness among fifth and ninth grade Ohio students: A continuing study. Ohio Journal of Science, 88(3), 106-109.

Fraser, B. J, & Tobin, K. (1988). Psychological environment in exemplary teachers' classrooms. Paper presented at the annual meeting of the National Association for Research in Science Teaching, Lake of the Ozarks, MO, April, 1988. (ERIC Document Reproduction Service No. ED 295 819)

Fraser, B. J., Tobin, K., & Lacy, T. (1988). A study of exemplary primary science teachers. Research in Science and Technological Education, 6(1), 25-38.

Fraser-Abder, P. (1988). Summary of science education research in the Caribbean 1970-1987. Paper presented at the annual meeting of the National Association for Research in Science Teaching, Lake of the Ozarks, April, 1988. (ERIC Document Reproduction Service No. ED 293 707)

Frieske, R. J. (1988). The influence of selected supplementary materials on standardized science achievement scores (Doctoral dissertation, Oregon State University, 1987). Dissertation Abstracts International, 49(4), 724-A.

Gan, S. (1988). Environmental education in Malaysia: Curriculum guidelines for preservice science teacher education programs (Doctoral dissertation, University of Hawaii, 1987). Dissertation Abstracts International, 49(2), 194-A.

Gayford, C. (1988). Aims, purposes and emphasis in practical biology at advanced level—A study of teachers' attitudes. School Science Review, 69(249), 799-802.

Geddis, A. N. (1988). Using concepts from epistemology and sociology in teacher supervision. Science Education, 72(1), 1-18.

Germann, P. J. (1988). Development of the attitude toward science assessment and its use to investigate the relationship between science achievement and attitude toward science in school. Journal of Research in Science Teaching, 25(8), 689-703.

Gilbert, S. W. (1988). Student knowledge of models and science: Some findings and relationships. Paper presented at the annual meeting of the National Association for Research in Science Teaching, Lake of the Ozarks, MO, April, 1988. (ERIC Document Reproduction Service No. ED 292 667)

Griffiths, A., Thomey, K., Cooke, B., & Normore, G. (1988). Remediation of student-specific misconception relating to three science concepts. Journal of Research in Science Teaching, 25(9), 709-719.

Grossman, E. B. (1988). Antecedent cognitive skills related to science inquiry: An assessment with deaf children (Doctoral dissertation, Columbia University Teachers College, 1987). Dissertation Abstracts International, 48(7), 1722-A.

Gunstone, R. F. (1988). Some long-term effects of uninformed conceptual change. Paper presented at the Annual Meeting of the American Educational Research Association, New Orleans, LA, April, 1988. (ERIC Document Reproduction Service No. ED 292 632)

Gunstone, R. F., White, R. T., & Fensham, P. J. (1988). Developments in style and purpose of research on the learning of science. Journal of Research in Science Teaching, 25(7), 513-529.

Gussarsky, E., & Gorodetsky, M. (1988). On the chemical equilibrium concept: Constrained work associations and conception. Journal of Research in Science Teaching, 25(5), 319-333.

Guyton, J. W. (1988). A comparison of the personality traits of secondary science teachers in Mississippi public schools (Doctoral dissertation, Mississippi State University, 1987). Dissertation Abstracts International, 48(10), 2592-A.

Hackling, M. W., & Lawrence, J. A. (1988). Expert and novice solutions of genetic pedigree problems. Journal of Research in Science Teaching, 25(7), 531-546.

Haggerty, S. M. (1988). Learning about heat and temperature: A study of a grade nine science class (Doctoral dissertation, The University of British Columbia, 1986). Dissertation Abstracts International, 48(9), 2302-A.

Haig, B. D. (1988). Meta-analysis: An inappropriate rationale for science education research. Journal of Research in Science Teaching, 25(1), 89-91.

Hall, D. A., & McCurdy, D. W. (1988). A comparison of a Biological Sciences Curriculum Study (BSCS) Laboratory and a traditional laboratory on student achievement at two private liberal arts colleges. Paper presented at the annual meeting of the National Association for Research in Science Teaching, Lake of the Ozarks, MO, April, 1988. (ERIC Document Reproduction Service No. ED 291 576)

Hardiman, P. T., Dufresne, R. J., & Mestre, J. P. (1988). The relation between problem categorization and problem solving among novices and experts. (ERIC Document Reproduction Service No. ED 294 753)

Harty, H., Kloosterman, P., & Ault, P. C. (1988). Mathematics-science related on-the-job concerns of immediate high school graduate employers. School Science and Mathematics, 88(8), 650-653.

Harty, H., Kloosterman, P., & Matkin, J. (1988). Surveying elementary and middle school mathematics and science instructional use. School Science and Mathematics, 88(8), 683-687.

Hashweh, M. (1988). Descriptive studies of students' conceptions in science. Journal of Research in Science Teaching, 25(2), 121-134.

Hauben, M. H., & Lehman, J. D. (1988). Computer assisted instruction for problem solving by dimensional analysis. Journal of Computers in Mathematics and Science Teaching, 7(3), 50-54.

Haukoos, G. D., & Chandayot, P. (1988). A cross-cultural study of attitude toward science and related influential factors. Paper presented at the annual meeting of the National Association for Research in Science Teaching, Lake of the Ozarks, MO, April, 1988. (ERIC Document Reproduction Service No. ED 291 591)

Haury, D. L. (1988). Evidence that science locus of control orientation can be modified through instruction. Journal of Research in Science Teaching, 25 (3), 233-246.

Heese, J. J. (1988). Student conceptions of chemical change (Doctoral dissertation, Michigan State University, 1987). Dissertation Abstracts International, 48(7), 1722-A.

Heikkinen, M. W. (1988). The academic preparation of Idaho science teachers. Science Education, 72(1), 63-71.

Heller, P., Padilla, M., Hertel, B., & Olstad, R. (1988). Learning about technology: Family vs. peer pairings. Journal of Research in Science Teaching, 25(1), 1-14.

Hendry, E. J. (1988). The status of elementary school science in New Hampshire public schools, grades K-6: Principals' and teachers' views (Doctoral dissertation, Boston University, 1987). Dissertation Abstracts International, 49(5), 1057-A.

Hewson, P. W., & Hewson, M. G. (1988a). An appropriate conception of teaching science: A view from studies of science learning. Science Education, 72 (5), 597-614.

Hewson, P. W., & Hewson, M. G. (1988b). Analysis and use of a task for identifying conceptions of teaching science. Paper presented at the annual meeting of the American Educational Research Association, New Orleans, LA, April, 1988. (ERIC Document Reproduction Service No. ED 293 724)

Heyworth, R. M. (1988). Mental representation of knowledge for a topic in high school chemistry (Doctoral dissertation, Stanford University, 1988). Dissertation Abstracts International, 49(6), 1409-A.

Hidayat, E. M. (1988). Student perceptions of science classes, science teachers, scientists, and the usefulness of science study in elementary and secondary schools in Bandund, Indonesia (Doctoral dissertation, University of Iowa, 1987). Dissertation Abstracts International, 49(4), 778-A.

Hinduan, A. A. (1988). The contributions of cognitive development and field-dependence-independence on secondary school science students' mastery of graphic skills (Doctoral dissertation, State University of New York at Albany, 1987). Dissertation Abstracts International, 48(8), 1935-A.

Hodson, D. (1988). Toward a philosophically more valid science curriculum. Science Education, 72(1), 19-41.

Hoff, D. B., Lancaster, R. P., Little, S. C., & Thompson, K. W. (1988). Earth science teaching in Iowa during the decade 1976 to 1986. Journal of Geological Education, 36(1), 19-23.

Hollon, R. E. (1988). Teachers' beliefs about students' learning processes in science: A descriptive study (Doctoral dissertation, Michigan State University, 1987). Dissertation Abstracts International, 49(1), 67-A.

Horwood, R. H. (1988). Explanation and description in science teaching. Science Education, 72(1), 41-49.

Howe, A. C. (1988). Translating research into practice: A model linking university researchers and classrooms teachers. Paper presented at the annual meeting of the National Association for Research in Science Teaching, Lake of the Ozarks, April, 1988. (ERIC Document Reproduction Service No. ED 292 618)

Huang, I. (1988). Student comprehension and teacher perception of tenth grade biology concept learning in the Republic of China (Doctoral dissertation, Indiana State University, 1987). Dissertation Abstracts International, 48(9), 2302-A.

Humrich, E. (1988). Sex differences in the second IEA science study—U.S. results in an international context. Paper presented at the annual meeting of the National Association for Research in Science Teaching, Lake of the Ozarks, MO, April, 1988. (ERIC Document Reproduction Service No. ED 292 649)

Inman, M. D. (1988). Assessing the use of science content readings in an elementary science methods course as a method of improving attitudes of students toward science and science teaching (Doctoral dissertation, University of South Florida, 1987). Dissertation Abstracts International, 48(10), 2592-A.

Jeong, J. (1988). The relationship between ninth grade achievement and tenth and eleventh grade science achievement in Korea (Doctoral dissertation, University of Georgia, 1987). Dissertation Abstracts International, 48(11), 2844-A.

Johnson, B. K., & Vitale, P. (1988). A factor analysis study of attitudes of gifted secondary students toward science. Paper presented at the annual meeting of the National Association for Research in Science Teaching, Lake of the Ozarks, MO, April, 1988. (ERIC Document Reproduction Service No. ED 291 560)

Jones, M. G. (1988). Gender differences in student-teacher interactions in physical and chemistry classes (Doctoral dissertation, North Carolina State University, 1987). Dissertation Abstracts International, 48(11), 2844-A.

Jones, M. G., & Wheatley, J. (1988). Factors influencing the entry of women into science and related fields. Science Education, 72(2), 127-142.

Kelly, A. (1988). Option choices for girls and boys. Research in Science and Technological Education, 6(1), 5-23.

Kimmel, H., Kerr, E. B., & O'Shea, M. (1988). Computer conferencing as a resource of in-service teacher education. Science Education, 72(4), 467-473.

Kinney, J. H. (1988). The effects of sign language lessons by a deaf student teacher, who uses an interpreter, on the perception and achievement of normal hearing ninth grade multicultural biology classes. (ERIC Document Reproduction Service No. ED 295 812)

Klockziem, R. C. (1988). Status of science teaching in the elementary schools of the Wisconsin Evangelical Lutheran Synod (Doctoral dissertation, University of Minnesota, 1987). Dissertation Abstracts International, 49(4), 779-A.

Kloosterman, P., Harty, H., & Woods, C. J. (1988). Administrators' eyeview of the instructional quality of secondary school science and mathematics. School Science and Mathematics, 88(4), 335-343.

Koballa, T. R., Jr. (1988a). Attitude and related concepts in science education. Science Education, 72(2), 115-126.

Koballa, T. R., Jr. (1988b). Persuading girls to take elective physical science courses in high school: Who are the credible communicators? Journal of Research in Science Teaching, 25(6), 465-478.

Koballa, T. R., Jr. (1988c). The determinants of female junior high school students' intentions to enroll in elective physical science courses in high school: Testing the applicability of the theory of reasoned action. Journal of Research in Science Teaching, 25(6), 479-492.

Koch, H., McGarry, M., & Patterson, P. (1988). User friendly research: An interactive computer software system combining teaching, learning, curriculum and research. Paper presented at the annual meeting of the National Association for Research in Science Teaching, Lake of the Ozarks, April, 1988. (ERIC Document Reproduction Service No. ED 292 654)

Kovacs, L. (1988). Pupils' thinking about some physical principles in England and Hungary. School Science Review, 69(248), 590-592.

Krajcik, J.S., Simmons, P. E., & Lunetta, V.N. (1988). A research strategy for the dynamic study of students' concepts and problem solving strategies using science software. Journal of Research in Science Teaching, 25(2), 147-155.

Krynowsky, B. A. (1988a). The relationship between student attitude toward grade 10 science and classroom learning environment variables (Doctoral dissertation, University of British Columbia, Canada, 1987). Dissertation Abstracts International, 49(5), 1107-A.

Krynowsky, B. A. (1988b). Problems in assessing student attitude in science education: A partial solution. Science Education, 72(5), 575-584.

Kyle, W. C., Bonnstetter, R. J., Gadsden, T., Jr. (1988). An implementation study: An analysis of elementary students' and teachers' attitudes toward science in process-approach vs. traditional science classes. Journal of Research in Science Teaching, 25(2), 103-120.

Kyle, W. C., Bonnstetter, R. J., Gadsden, T., Jr., & Shymansky, J. A. (1988). What research says. . . about hands on science. Science and Children, 25(7), 39-40, 52.

Laforgia, J. (1988). The affective domain related to science education and its evaluation. Science Education, 72(4), 407-421.

Lavoie, D. R., & Good, R. (1988). The nature and use of prediction skills in a biological computer simulation. Journal of Research in Science Teaching, 25(5), 335-360.

Law, N. (1988). Knowledge structures: Where can we find them? Paper presented at the Annual Meeting of the American Educational Research Association, New Orleans, LA, April, 1988. (ERIC Document Reproduction Service No. ED 294 922)

Lawrenz, F. (1988). Prediction of student energy knowledge and attitudes. School Science and Mathematics, 88(7), 543-549.

Lawrenz, F., & McCreath, H. (1988a). Integrating quantitative and qualitative evaluation methods to compare two teachers inservice training programs. Journal of Research in Science Teaching, 25 (5), 397-407.

Lawrenz, F., & McCreath, H. (1988b). Native American school environment: Focus on science and mathematics education. School Science and Mathematics, 88(8), 676-682.

Lawson, A. E. (1988). The acquisition of biological knowledge during childhood: Cognitive conflict or tabula rosa? Journal of Research in Science Teaching, 25(3), 185-199.

Lawson, A. E., & Thompson, L. D. (1988). Formal reasoning ability and misconceptions concerning genetics and natural selection. Journal of Research in Science Teaching, 25(9), 733-746.

Lazarowitz, R., Hertz, R. L., Baird, J. H., & Bowlden, V. (1988). Academic achievement and on-task behavior of high school biology students instructed in a cooperative small investigative group. Science Education, 72(4), 475-487.

Ledbetter, C. E. (1988). An investigation of the theoretical orientations of eighth grade students and their teachers to science (Doctoral dissertation, Texas A&M University, 1987). Dissertation Abstracts International, 49(4), 715-A.

Legorreta, C. M. (1988). A study of related factors in high school science curricula relating to science, technology, and society (Doctoral dissertation, New Mexico State University, 1988). Dissertation Abstracts International, 49(5), 1108-A.

Lehman, J. D. (1988). Integrating computers in biology education of elementary teaching majors. Paper presented at the annual meeting of the National Association for Research in Science Teaching, Lake of the Ozarks, April, 1988. (ERIC Document Reproduction Service No. ED 291 579)

Lehman, J. R., & McDonald, J. L. (1988). Teachers' perceptions of the integrations mathematics and science. School Science and Mathematics, 88 (8), 642-649.

Leith, S. (1988). Classroom-based diagnosis and assessment in primary science. (ERIC Document Reproduction Service No. ED 292 650)

Lenk, A. J. (1988). The perception of science teaching among elementary teachers and its relationship to time and method of instruction (Doctoral dissertation, George Peabody College for Teachers of Vanderbilt University, 1987). Dissertation Abstracts International, 49(4), 779-A.

Lerner, L. S., & Bennetta, W. J. (1988). The treatment of theory in textbooks. The Science Teacher, 55(4), 37-41.

Liske, R. L. (1988). High school students as collaborators in the development of a science curriculum. Paper presented at the annual meeting of the National Association for Research in Science Teaching, Lake of the Ozarks, MO, April, 1988. (ERIC Document Reproduction Service No. ED 291 587)

Lombardi, A. R. (1988). Attitudes of science chairpersons toward science-technology-society issues (Doctoral dissertation, Boston University, 1988). Dissertation Abstracts International, 49(3), 47-A.

Lord, T. R. (1989). Is the final grade in college biology a true measure of student knowledge? Paper presented at the annual meeting of the National Association for Research in Science Teaching, Lake of the Ozarks, MO, April, 1988. (ERIC Document Reproduction Service No. ED 297 936)

Lucas, A. M. (1988). Public knowledge of elementary physics. Physics Education, 23(1), 10-16.

Maarschalk, J. (1988). Scientific literacy and informal science teaching. Journal of Research in Science Teaching, 25(2), 135-146.

Macdonald, M. A., & Rogan, J. M. (1988). Innovation in South Africa science education (Part I): Science teaching observed. Science Education, 72 (2), 225-236.

Maloney, D. P. (1988). Novice rules for projectile motion. Science Education, 72(4), 501-513.

Maroufi, C. (1988). A comparative study of generative and traditional methods of science instruction (Doctoral dissertation, University of California, Los Angeles, 1987). Dissertation Abstracts International, 48(7), 1722-A.

Marsick, D. J., & Thornton, S. F. (1988). Safety tips: Science teacher safety survey. Journal of Chemical Education, 65(5), 448-449.

Martens, M. L. (1988). Implementation of a problem solving curriculum for elementary science: Case studies of teachers in change (Doctoral dissertation, St. John's University, 1988). Dissertation Abstracts International, 49(4), 716-A.

Martin, L. M. (1988). Teaching problem structure from video and everyday life. Paper presented at the Annual Meeting of the American Educational Research Association, New Orleans, LA, April, 1988. (ERIC Document Reproduction Service No. ED 296 878)

Mawande, N. M. (1988). An examination of the status of science education and emerging science needs as perceived by key persons in Botswana, Malawi, Zambia, and Zimbabwe (Doctoral dissertation, University of Texas at Austin, 1987). Dissertation Abstracts International, 48(7), 1723-A.

McCammon, S., Golden, J., Wuensch, K. L. (1988). Predicting course performance in freshman and sophomore physics courses: Women are more predictable than men. Journal of Research in Science Teaching, 25(6), 501-510.

McCollum, T. L. (1988). The effect of animal dissection on student acquisition of knowledge of and attitudes toward animals dissected. Paper presented at the annual meeting of the National Association for Research in Science Teaching, Lake of the Ozarks, MO, April, 1988. (ERIC Document Reproduction Service No. ED 294 749)

McCurry, E. N. (1988). The effects of microcomputer drill and practice on achievement and attitude in general physics classes at a two year liberal art college (Doctoral dissertation, University of Georgia, 1988). Dissertation Abstracts International, 49(5), 1108-A.

McIntosh, W. J., & Zeidler, D. L. (1988). Teachers' conceptions of the contemporary goals of science education. Journal of Research in Science Teaching, 25(2), 93-102.

Mehl, M. C. (1988). The cognitive difficulties of first year physics students at the University of the Western Cape and various compensatory programmes (Doctoral dissertation, University of Cape Town, South Africa, 1985). Dissertation Abstracts International, 49(4), 779-A.

Meissner, L. L. (1988). A profile of the science teaching needs and concerns of elementary school teachers in a parochial setting (Doctoral dissertation, University of Texas at Austin, 1987). Dissertation Abstracts International, 49(3), 474-A.

Melear, C. T. (1988). Perceptions of research scientists and science educators regarding science education: Call for synergy. Paper presented at the annual meeting of the National Association for Research in Science Teaching, Lake of Ozarks, MO, April, 1988. (ERIC Document Reproduction Service No. ED 294 737)

Menis, J. H. (1988). Student perceptions of the conditions of learning the proportion concept in Canadian upper secondary science (physics, chemistry, biology) classes; Results from the Second International Science Study (S.I.S.S.) in Canada. Journal of Research in Science Teaching, 25(3), 225-232.

Merkle, D. G., Treagust, D. F. (1988). Student knowledge of health and fitness concepts and its relation to locus of control. Paper presented at the annual meeting of the National Association for Research in Science Teaching, Lake of the Ozarks, MO, April, 1988. (ERIC Document Reproduction Service No. ED 291 583)

Mesaros, R. A. (1988). The effect of teaching strategies on the acquisition and retention of knowledge: An exploratory quasi-experimental study using a science/technology/society teaching strategy versus a traditional approach with tenth grade biology and ninth grade physical science students (Doctoral dissertation, University of Pennsylvania, 1987). Dissertation Abstracts International, 49(2), 229-A.

Metz, P. A. (1988). The effect of interactive instruction and lectures on the achievement and attitudes of chemistry students (Doctoral dissertation, Purdue University, 1987). Dissertation Abstracts International, 49(3), 474-A.

Meyer, L. A., Crummey, L., & Greer, E. A. (1988). Elementary science textbooks: Their content, text characteristics and comprehensibility. Journal of Research in Science Teaching, 25(6), 435-463.

Miller, R. H. (1988). Adding relevance to science teaching through outdoor education (Doctoral dissertation, University of Wisconsin-Milwaukee, 1987). Dissertation Abstracts International, 48(11), 2844-A.

Mitchell, A., & Lawson, A. E. (1988). Predicting genetics achievement in non college biology. Journal of Research in Science Teaching, 25(1), 23-37.

Mitchell, K. L. (1988). Computer utilization in Texas secondary science classrooms (Doctoral dissertation, University of Texas, 1987). Dissertation Abstracts International, 49(5), 1108-A.

Mohapatra. J. K. (1988). Induced incorrect generalizations leading to misconceptions: An exploratory investigation about the laws of reflection of light. Journal of Research in Science Teaching, 25(9), 777-784.

Mousa, N. A. (1988). The effects of CAI tutorial instruction on college students' achievement and skills performance in balancing chemical equations (Doctoral dissertation, University of Pittsburgh, 1987). Dissertation Abstracts International, 49(4), 717-A.

Muthwii, S. M. (1988). Classroom discourse in chemistry: A study of the teacher pupil discourse events in some Kenyan chemistry classrooms (Doctoral dissertation, University of East Anglia, U.K., 1987). Dissertation Abstracts International, 49(1), 68-A.

Nakayama, G. (1988). A study of the relationship between cognitive style and integrated science process skills. Paper presented at the annual meeting of the National Association for Research in Science Teaching, Lake of the Ozarks, MO, April, 1988. (ERIC Document Reproduction Service No. ED 291 592)

Nelson, D. N. (1988). Parental knowledge of course objectives and grades of high school physical science students. (ERIC Document Reproduction Service No. ED 295 845)

Niaz, M. (1988a). Manipulation of M-demand of chemistry problems and its effect on student performance: A Neo-Piagetian study. Journal of Research in Science Teaching, 25(8), 643-657.

Niaz, M. (1988b). Student performance in water pouring and balance beam tasks: Effect of manipulation of perceptual field factor. Research in Science and Technological Education, 6(1), 39-50.

Noraas, M. (1988). SCIIS—Through the eyes of teachers. School Science and Mathematics, 88(4), 284-294.

O'Brien, T. P. (1988). A concerns-based field study of a chemical demonstration inservice program (Doctoral dissertation, University of Maryland, 1987). Dissertation Abstracts International, 48(11), 2851-A.

O'Non, J. E. (1988). Effects of a specially designed physical science course on prospective elementary teachers' attitudes, knowledge and skills towards the learning and teaching of science (Doctoral dissertation, Michigan State University, 1987). Dissertation abstracts international, 49(3), 474-A.

O'Sullivan, K. A., & Zielinski, E. J. (1988). Development of stages of concern questionnaire for preservice teachers. Paper presented at the annual meeting of the National Association for Research in Science Teaching, Lake of the Ozarks, MO, April, 1988. (ERIC Document Reproduction Service No. ED 295 811)

Ofelt, C. H. (1988). An analysis of attitudes of participants involved in an interdisciplinary National Science Foundation summer institute at Montana State University (Doctoral dissertation, Montana State University, 1986). Dissertation abstracts international, 48(11), 2844-A.

Okebukola, P. A., & Jegede, O. J. (1988). Cognitive preference and learning mode as determinants of meaningful learning through concept mapping. Science Education, 72(4), 489-500.

Okpala, P., & Onocha, C. (1988). Difficult physics topics in Nigerian secondary schools. Physics Education, 23(3), 168-172.

Olarewaju, A. O. (1988). Instructional objectives: What effects do they have on students' attitudes toward integrated science? Journal of Research in Science Teaching, 25(4), 283-291.

Oliver, J. S., & Simpson, R. D. (1988). Influences of attitude toward science, achievement motivation, and science self concept on achievement in science: A longitudinal study. Science Education, 72(2), 143-155.

Osmasta, E., & Lunetta, V. N. (1988). Exploring functions: A strategy for teaching physics concepts and problem-solving. Science Education, 72(5), 625-636.

Ostojic, D. B. Evaluation and improvement of placement procedures in general chemistry (Doctoral dissertation, University of Illinois at Chicago, 1987). Dissertation Abstracts International, 48(10), 2593-A.

Osuagwu, N. N. (1988). Relationships between students' antecedent knowledge, cognitive development, and achievement in genetics (Doctoral dissertation, Columbia University Teachers College, 1987). Dissertation Abstracts International, 49(1), 68-A.

Pallrand, G. J. (1988). Knowledge representation in novice physics problem solvers. Paper presented at the Annual Meeting of the National Association for Research in Science Teaching, Lake Ozark, MO, April, 1988. (ERIC Document Reproduction Service No. ED 292 634)

Pankratius, W. J. (1988). Building an organized knowledge base: Concept mapping and achievement in secondary school physics (Doctoral dissertation, Georgia State University, 1987). Dissertation Abstracts International, 49(3), 474-A.

Pauline, R. F, & Bell, P. E. (1988). The effects of slide/sound computer based instruction on students' achievement and retention. Paper presented at the annual meeting of the National Association for Research in Science Teaching, Lake of the Ozarks, MO, April, 1988. (ERIC Document Reproduction Service No. ED 292 673)

Pauline, R. F. (1988). The impact of content feedback and review on ninth grade students' learning of Earth's history using interactive slide/sound computer instruction (Doctoral dissertation, Pennsylvania State University, 1987). Dissertation Abstracts International, 48(10), 2593-A.

Pedersen, J., Bonnstetter, R. J., Corkill, A. J., & Glover, J. A. (1988). Learning chemistry from text: The effect of decision-making. Journal of Research in Science Teaching, 25(1), 15-21.

Piburn, M., Baker, D., & Treagust, D. (1988). Misconceptions about gravity held by college students. Paper presented at the Annual Meeting of the National Association for Research in Science Teaching, Lake Ozark, MO, April, 1988. (ERIC Document Reproduction Service No. ED 292 616)

Pirkle, S. F., & Pallrand, G. J. (1988). Knowledge representation about projectile motion in junior high school students. Paper presented at the Annual Meeting of the National Association for Research in Science Teaching, Lake Ozark, MO, April, 1988. (ERIC Document Reproduction Service No. ED 294 739)

Powell, R. R., & Garcia, J. (1988). What research says . . . about stereotypes. Science and Children, 25(5), 21-23.

Prather, J. P., & Field, M. H. (1988). Enriching elementary science instruction through joint training of inservice teachers, principals, and instructional supervisors. Paper presented at the annual meeting of the National Association for Research in Science Teaching, Lake of the Ozarks, MO, April, 1988. (ERIC Document Reproduction Service No. ED 291 584)

Preece, P. F. (1988). A decade of research in science education. School Science Review, 69(248), 579-586.

Proper, H., Wideen, M. F., & Ivany, G. (1988). World view projected by science teachers: A study of classroom dialogue. Science Education, 72(5), 547-560.

Purepong, W. (1988). Relationships between Thai preservice teacher sciencing self concept and five teaching-learning effective attributes (Doctoral dissertation, Indiana University, 1987). Dissertation Abstracts International, 48(10), 2593-A.

Radford, D. L. (1988). Integrated process skill instruction into the traditional science curriculum. Paper presented at the annual meeting of the National Association for Research in Science Teaching, Lake of the Ozarks, MO, April, 1988. (ERIC Document Reproduction Service No. ED 291 588)

Renner, J. W., Abraham, M. R., & Birnie, H. H. (1988). The necessity of each phase of the learning cycle in teaching high school physics. Journal of Research in Science Teaching, 25(1), 39-58.

Reynolds, F. E. (1988). Writing as a way of learning in a tenth grade biology class (Doctoral dissertation, University of Missouri-Columbia, 1987). Dissertation Abstracts International, 48(9), 2237-A.

Ridgeway, D. (1988). Misconceptions and the qualitative method. Science Teacher, 55(6), 68-71.

Rochford, K. (1988). An investigation into the attainment of spatial concepts by university science students (Doctoral dissertation, University of Cape Town, South Africa, 1984). Dissertation Abstracts International, 49(2), 229-A.

Roelfs, F. C. (1988), Academic factors affecting the status of the teaching of evolution in Arkansas and Missouri (Doctoral dissertation, University of Missouri-Columbia, 1987). Dissertation Abstracts International, 48(10), 2593-A.

Rogan, J. M. Development of a conceptual framework of heat. Science Education, 72(1), 103-113.

Rose, R. L. (1988). Improving remedial students' approaches to proportional thinking in science (Doctoral dissertation, George Mason University, 1987). Dissertation Abstracts International, 48(10), 2594-A.

Roth, W. (1988). A Neo-Piagetian approach to the development of problem solving strategies in the domain of proportion problems (Doctoral dissertation, The University of Southern Mississippi, 1987). Dissertation Abstracts International, 49(4), 780-A.

Rowland, P.M. (1988). The effect of two modes of computer-assisted instruction and individual learning differences on the understanding of science concept relationships (Doctoral dissertation, New Mexico State University, 1988). Dissertation Abstracts International, 49(4), 780-A.

Sanford, J. P. (1988). Learning on the job: Conditions for professional development of beginning science teachers. Science Education, 72(5), 615-624.

Saunders, W., & Jesunathadas, J. (1988). The effect of task content upon proportional reasoning. Journal of Research in Science Teaching, 25(1), 59-67.

Sayers, M. P. (1988). The relationship of self-efficacy expectations, interests, and academic ability to the selection of science and non-science majors (Doctoral dissertation, University of Kansas, 1987). Dissertation Abstracts International, 48(10), 2544-A.

Scallan, B. P. (1988). The effect of guided practice on student achievement in social studies and science in grades five and six (Doctoral dissertation, North Texas State University, 1987). Dissertation Abstracts International, 48(8), 1981-A.

Scharmann, L. C. (1988a). The influences of sequenced instructional strategy and locus of control on preservice elementary teachers' understanding of the nature of science. Journal of Research in Science Teaching, 25(7), 589-604.

Scharmann, L. C. (1988b). Locus of control: A discriminator of the ability to foster an understanding of the nature of science among preservice elementary teachers. Science Education, 72(4), 453-465.

Schmidt, H. (1988). Mind the red herrings—Deliberate distraction of pupil's strategies solving multiple choice questions in chemistry. (ERIC Document Reproduction Service No. ED 291 577)

Schultz, K., & Lochhead, J. (1988). Toward a unified theory of problem solving: A view from physics. Paper presented at the Annual Meeting of the American Educational Research Association, New Orleans, LA, April, 1988. (ERIC Document Reproduction Service No. ED 295 795)

Scott, J. P. (1988). Interaction in rural science class. A naturalistic study. Paper presented at the annual meeting of the American Educational Research Association, New Orleans, April, 1988. (ERIC Document Reproduction Service No. ED 296 877)

Sellars, G. B. (1988). A comparison of the readability of selected high school social studies, science, and literature textbooks (Doctoral dissertation, Florida State University, 1987). Dissertation Abstracts International, 48(12), 3085-A.

Sevenair, J. P., & Burkett, A. R. (1988). Difficulty and discrimination of multiple-choice questions: A counterintuitive result. Journal of Chemical Education, 65(5), 441-442.

Shapiro, B. L. (1988). What children bring to light: A study of personal orientation to science learning (Doctoral dissertation, University of Alberta, 1987). Dissertation Abstracts International, 48(10), 2530-A.

Shapiro, M. A. (1988). Components of interest in television science stories. Paper presented at the annual meeting of the Association for Education in Journalism and Mass Communication, Portland, OR, July, 1988. (ERIC Document Reproduction Service No. 296 400)

Shaw, E. L., McKenzie, D., & Kuehn, C. (1988). Assessing the skill of variable identification with multiple choice items. Paper presented at the annual meeting of the National Association for Research in Science Teaching, Lake of the Ozarks, MO, April, 1988. (ERIC Document Reproduction Service No. ED 292 663)

Shemesh, M., & Lazarowitz, R. (1988a). Formal reasoning skills of secondary school students and their subject matter preferences. School Science and Mathematics, 88(5), 376-389.

Shemesh, M., & Lazarowitz, R. (1988b). The interactional effects of students' cognitive levels and test characteristics on the performance of formal reasoning tasks. Research in Science and Technological Education, 6(1), 79-89.

Shmaefsky, B. R. (1988). College science student cognitive style as a factor for student evaluation of college instruction (Doctoral dissertation, Southern Illinois University at Edwardsville, 1987). Dissertation Abstracts International, 48(12), 3044-A.

Shrigley, R. L., Koballa, T. R., & Simpson, R. D. (1988). Defining attitude for the science educator. Journal of Research in Science Teaching, 25(8), 659-678.

Shroyer, M. G. (1988). Community, organizational, professional, and procedural factors that influence rural science teachers as leaders of district improvement projects (Doctoral dissertation, Kansas State University, 1987). Dissertation Abstracts International, 48(8), 1973-A.

Shyu, Y. (1988). The use of a microcomputer-based classroom simulation in the preparation of secondary science teachers (Doctoral dissertation, University of Michigan, 1987). Dissertation Abstracts International, 49(2), 229-A.

Simmons, P. E. (1988). Problem solving behaviors and concepts of novices and experts during interaction with a genetics computer simulation (Doctoral dissertation, The University of Iowa, 1987). Dissertation Abstracts International, 48(7), 1723-A.

Simpson, E. D., & Marek, E. A. (1988). Understanding and misconceptions of biology concepts held by students attending small high schools and students attending large high schools. Journal of Research in Science Teaching, 25(5), 361-374.

Smith, M. U. (1988a). Successful and unsuccessful problem solving in classical genetic pedigrees. Journal of Research in Science Teaching, 25(6), 411-433.

Smith, M. U. (1988b). Expertise, mental representations, and problem-solving success: A study of the categorizations of classical genetics problems by biology faculty, genetic counselors, and students. Paper presented at the Annual Meeting of the National Association for Research in Science Teaching, Lake Ozark, MO, April, 1988. (ERIC Document Reproduction Service No. ED 292 674)

Snir, J., Smith, C., & Grosslight, L. (1988). The truth, but not the whole truth: An essay on building a conceptually enhanced computer simulation for science teaching. (Technical Report 88-18). (ERIC Document Reproduction Service No. ED 295 832)

Staver, J. R., & Jacks, T. (1988). The influence of cognitive reasoning level, cognitive restructuring ability, disembedding ability, working memory capacity, and prior knowledge on students' performance on balancing equations by inspection. Journal of Research in Science Teaching, 25(9), 763-775.

Stepans, J., Dyche, S., & Beiswenger, R. (1988). The effect of two instructional modules in bringing about a conceptual change in the understanding of science concepts by prospective elementary teachers. Science Education, 72 (2), 185-195.

Stewart, J. (1988). Potential learning outcomes from solving genetics problems: A typology of problems. Science Education, 72(2), 237-254.

Subotnik, R. F. (1988). Factors from the structure of intellect model associated with gifted adolescents' problem finding in science: Research with Westinghouse science talent search winners. Journal of Creative Behavior, 22(1), 42-54.

Susilo, H. (1988). Perceived needs for students planning to study college biology in the United States and Indonesia (Doctoral dissertation, University of Iowa, 1987). Dissertation Abstracts International, 49(1), 68-A.

Tamir, P. (1988a). The role of pre-planning curriculum evaluation in science education. Journal of Curriculum Studies, 20(3), 257-262.

Tamir, P. (1988b). The relationship between cognitive preferences, student background and achievement. Journal of Research in Science Teaching, 25(3), 201-216.

Tobin, K., & Fraser, B. J. (1988). Investigations of exemplary practice in science and mathematics in Western Australia. Journal of Curriculum Studies, 20(4), 369-371.

Tobin, K., & Garnett, P. (1988). Exemplary practices in science classrooms. Science Education, 72(2), 197-208.

Tobin, K., Espinet, M., Byrd, S. E., & Adams, D. (1988). Alternative perspectives of effective science teaching. Science Education, 72(4), 433-451.

Tobin, K., Treagust, D. F., Fraser, B. J. (1988). An investigation of exemplary biology teaching. The American Biology Teacher, 50(3), 142-147.

Tolman, R. R., Baird, J. H., & Haderlie, S. (1988). A study of science education graduates at Brigham Young University. Science Education, 72(1), 93-101.

Tomkiewicz, W.C. (1988). The functional paradigms of high school biology teachers (Doctoral dissertation, Boston University, 1987). Dissertation Abstracts International, 48(7), 1724-A.

Tracy, D. M. (1988). Toy-playing behavior, sex-role orientation, spatial ability, and science achievement of fifth grade students: Are they related? Paper presented at the annual meeting of the National Association for Research in Science Teaching, Lake of the Ozarks, MO, April, 1988. (ERIC Document Reproduction Service No. ED 291 581)

Trowbridge, J. E., & Mintzes, J. J. (1988). Alternative conceptions in animal classification: A cross-age study. Journal of Research in Science Teaching, 25(7), 547-571.

Vachon, M. K. (1988). Development of a procedure for determining the level of abstraction of science reading materials (Doctoral dissertation, University of Wisconsin-Milwaukee, 1987). Dissertation Abstracts International, 48(10), 2531-A.

Vachon, M. K., & Haney, R. E. (1988). A procedure for determining the level of abstraction of science reading material. Paper presented at the annual meeting of the National Association for Research in Science Teaching, Lake of the Ozarks, MO, April, 1988. (ERIC Document Reproduction Service No. ED 291 582)

Vlahov, S. J., & Treagust, D. F. (1988). Students' knowledge of energy and attitudes to energy conservation. School Science and Mathematics, 88(6), 452-458.

Wacharayothin, S. (1988). The effects of teacher training on teacher wait-time, teacher questioning behavior and student cognitive achievement in chemistry (Doctoral dissertation, University of Maryland, 1987). Dissertation Abstracts International, 48(8), 1975-A.

Wandersee, J. H. (1988). Ways students read books. Journal of Research in Science Teaching, 25(1), 69-84.

Watts, M. (1988). From concept maps to curriculum signposts. Physics Education, 23(2), 74-79.

Watts, M., & Bentley, D. (1988). Down the tubes—viewers' opinions of science education television in the classroom. School Science Review, 69(248), 451-459.

Wells, M. H. (1988). Modeling instruction in high school physics (Doctoral dissertation, Arizona State University, 1987). Dissertation Abstracts International, 49(3), 424-A.

Westbrook, S. L. (1988). A cross-age study of student understanding of four biology concepts (Doctoral dissertation, The University of Oklahoma, 1987). Dissertation Abstracts International, 49(1), 69-A.

Wier, E. A. (1988). Braking down barriers to teaching primary science: Did a summer science institute help? Paper presented at the annual meeting of the National Association for Research in Science Teaching, Lake of the Ozarks, MO, April, 1988. (ERIC Document Reproduction Service No. ED 292 686)

Wilkinson, W. J., Treagust, D. F., Leggett, M., & Glasson, P. (1988). The teaching-learning environment in a student centered physics classroom. Paper presented at the annual meeting of the National Association for Research in Science Teaching, Lake of the Ozarks, MO, April, 1988. (ERIC Document Reproduction Service No. ED 292 619)

Williams, I. W., & Buseri, J. C. (1988). Expository teaching styles of Nigerian science teachers. Part 1: The science teaching observation schedule. Journal of Science and Technological Education, 6(1), 51-59.

Williams, K. J. (1988). An analysis of factors that determine the use of inquiry methods among secondary science teachers (Doctoral dissertation, Georgia State University, 1987). Dissertation Abstracts International, 48(9), 2233-A.

Williams, T. H. (1988). Certified science and math teachers who are not teaching: Reforms in the conditions of teaching required to encourage them to return or enter teaching (Doctoral dissertation, Virginia Polytechnic Institute and State University, 1987). Dissertation Abstracts International, 48(8), 1958-A.

Wilson, B. (Ed.). (1988). Making sense of the future. A position paper on the role of technology in science, mathematics, and computing education. (ERIC Document Reproduction Service No. ED 289 743)

Winn, W. (1988). Recall of the pattern, sequence, and names of concepts presented in instructional diagrams. Journal of Research in Science Teaching, 25(5), 375-386.

Wood, M. A., & Churchman, D. (1988). Extending the curriculum of zoomobiles. Paper presented at the Western Regional Meeting of the American Association of Zoological Parks and Aquariums, Monterey, CA, March, 1988. (ERIC Document Reproduction Service No. ED 291 593)

Wood, T. (1988). State-mandated accountability as a constraint on teaching and learning science. Journal of Research in Science Teaching, 25(8), 631-641.

Wood, T. L., & Wood, W. L. (1988). Assessing potential difficulties in comprehending fourth grade science textbooks. Science Education, 72(5), 561-574.

Woodson, L. Y. (1988). The relationship of self-concept as a learner, locus of control, and attitudes toward science to science achievement of males and females in junior high school (Doctoral dissertation, University of Pittsburgh, 1987). Dissertation Abstracts International, 48(8), 1976-A.

Worth, C., & Hanne, L. (1988). Undergraduate biology curriculum survey. (ERIC Document Reproduction Service No. ED 296 897)

Wright, R. G. (1988). The impact of grading and grading related factors on science attitude and science achievement motivation (Doctoral dissertation, University of Maryland, 1987). Dissertation Abstracts International, 48(8), 2035-A.

Yager, R. E. (1988a). Comparison of perceptions: Exemplary science and random programs. School Science and Mathematics, 88(1), 37-46.

Yager, R. E. (1988b). Assessing the impact of the Iowa honors workshop on science teachers and students. A final report for NSF. (ERIC Document Reproduction Service No. ED 292 626)

Yager, R. E. (1988c). Differences between most and least effective science teachers. School Science and Mathematics, 88(4), 301-307.

Yager, R. E., & Penick, J. E. (1988). Changes in perceived attitudes toward the goals for science instruction in schools. Journal of Research in Science Teaching, 25(3), 179-184.

Yager, R. E., Blunck, S. M., Binadja, A., McComas, W. F., & Penick, J. E. (1988). Assessing impact of S/T/S instruction on 4-9 science in five domains. (ERIC Document Reproduction Service No. ED 292 641)

Yager, R. E., Hidayat, E. M., & Penick, J. E. (1988). Features which separate least effective from most effective science teachers. Journal of Research in Science Teaching, 25(3), 165-177.

Yager, R. E., Snider, B., & Krajcik, J. (1988). Relative success in college chemistry for students who experienced a high-school course in chemistry and those who had not. Journal of Research in Science Teaching, 25(5), 387-396.

Yap. K. C., & Yeany, R. H. (1988). Validation of hierarchical relationships among Piagetian cognitive models and integrated science process skills for different cognitive reasoning levels. Journal of Research in Science Teaching, 25(4), 247-281.

Yurkewicz, W. (1988). The relationship among teacher behaviors, science anxiety, and success in science (Doctoral dissertation, University of New York at Albany, 1987). Dissertation Abstracts International, 49(5), 1108-A.

Zeitoun, H. H. (1988). The relationship between abstract concept achievement and prior knowledge, formal reasoning ability, and sex among some Egyptian secondary school students. Paper presented at the annual meeting of the National Association for Research in Science Teaching, Lake of the Ozarks, MO, April, 1988. (ERIC Document Reproduction Service No. ED 292 636)

Zoller, U., Ebenezer, J., Morley, K., Paras, S., Sandberg, V., West, C., Wolthers, & Tan, S. H. (1988). Goal attainment in science-technology-society (S/T/S) education: Expectations and Reality. A probe into the case of British Columbia. (ERIC Document Reproduction Service No. ED 293 690)

Zuman, J. P., & Weaver, S. L. (1988). Tools for teaching problem solving: An evaluation of a modeling and systems thinking approach. Paper presented at the Annual Meeting of the National Association for Research in Science Teaching, Lake Ozark, MO, April, 1988. (ERIC Document Reproduction Service No. ED 292 656)